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MARINE ENVIRONMENTAL ASSESSMENT AT THREE SITES IN PEARL HARBOR,--ETC(U)
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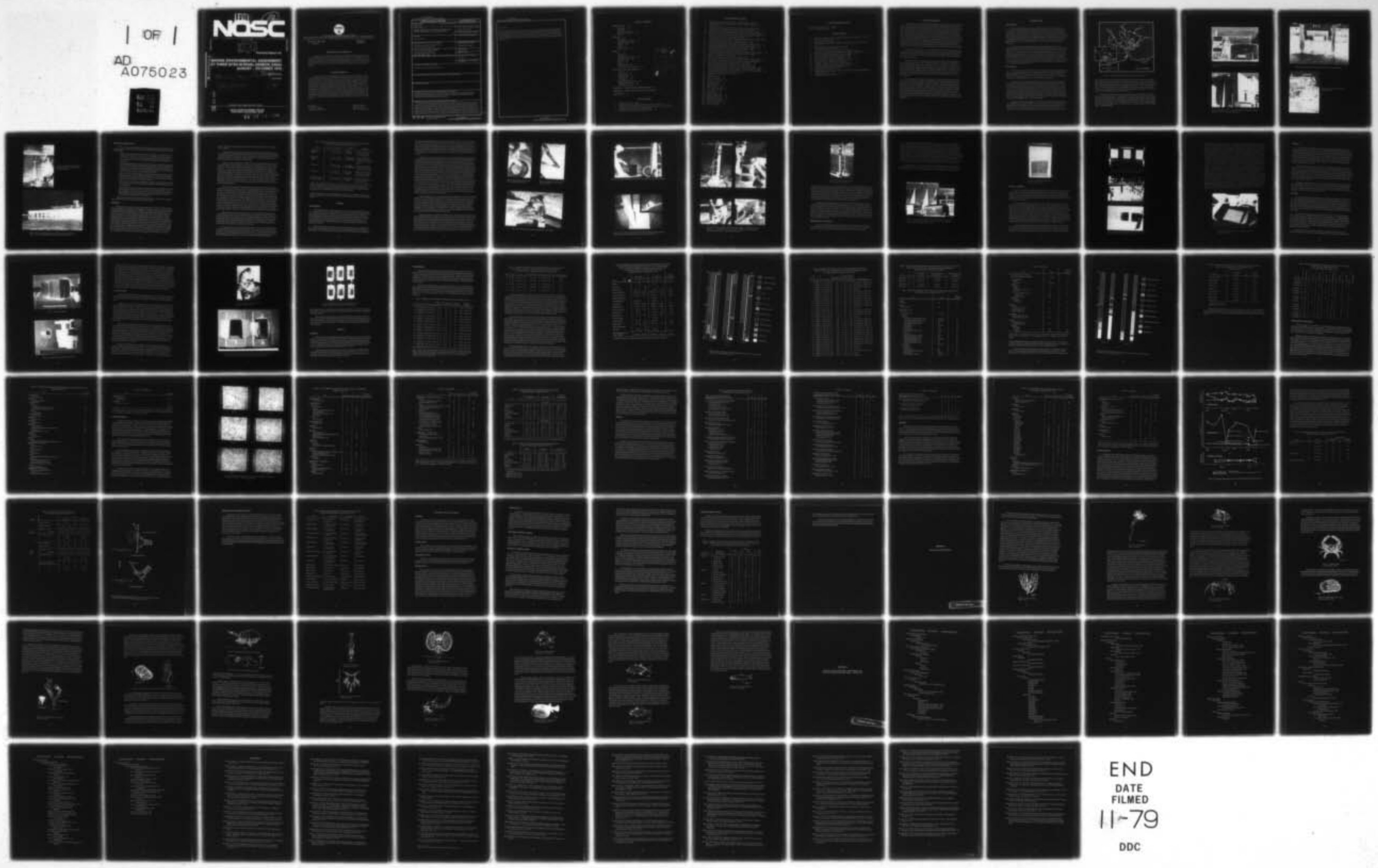

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MARINE ENVIRONMENTAL ASSESSMENT AT THREE SITES IN PEARL HARBOR, OAHU AUGUST - OCTOBER 1978

(9) Final Rept. Aug - Oct 78,

(10) Joseph G. Grovhoug

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ADMINISTRATIVE INFORMATION

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Marine environmental investigations were conducted at three sites in Pearl Harbor, Oahu, during the period Aug-Oct 78. Data were obtained from planktonic, epifaunal, nektonic and benthic assemblages of the resident ecosystem. These studies were designed to evaluate the impact from cooling water systems (both intake and discharge effects) in areas adjacent to study sites. Entrainment, impingement and entrapment were judged to be the primary intake factors capable of causing adverse impact. Elevated temperatures of effluent cooling water were considered the major discharge perturbation. Analysis of data suggests that minor, localized adverse impacts from cooling water systems occur at the two former power plant sites in Pearl Harbor. No impact from the Submarine

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Training Center discharge was detected. The harbor contains a complex estuarine ecosystem which has undergone many changes due to human activities. Present ecological conditions indicate that harbor biota have a remarkable resiliency to various perturbations. Representative important species of harbor organisms have been selected and are discussed in relation to cooling water system impacts. Tabulations of data collected, listing of organisms identified and detailed descriptions of marine environmental survey techniques used during this study are presented.

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EXECUTIVE SUMMARY

This report describes marine environmental investigations performed at three locations in Pearl Harbor, Oahu; former Power Plant 2 (Pearl Harbor Naval Shipyard), former Power Plant 3 (Hospital Point) and the Submarine Training Center (Ford Island). Naval Ocean Systems Center personnel from the Hawaii Laboratory conducted these studies at the request of Naval Facilities Engineering Command, Pacific Division, Makalapa, Hawaii. Field studies were initiated to measure quantitatively the effects of these installations on marine biota in the vicinity of intake and discharge structures in compliance with PL-92-500 and Chapter 37A of the Hawaii Public Health Regulations. More specifically, preliminary Section 316(a) and 316(b) studies under the provisions of the Federal Water Pollution Control Act Amendments of 1972 were performed. Administrative authority for 316(a) decisions and the establishment of zones of mixing under the National Pollution Discharge Elimination System (NPDES) has been delegated to the Department of Health, State of Hawaii. Cooling water intake structure evaluations 316(b) are administered by the Environmental Protection Agency.

Since the study sites are located in the same region of Pearl Harbor, the survey team used identical assessment methods for each site and the data obtained are highly interrelated, the results of these investigations have been assembled into a single document. However, at the request of the sponsor, each site has been evaluated separately to facilitate reporting to the appropriate agencies.

Sampling was directed toward important components of the marine ecosystem (i.e., those biota representative in terms of a balanced indigenous community; commercially or recreationally valuable; threatened or endangered; critical to the structure and function of the ecosystem, such as habitat formers; nuisance species; those organisms necessary in the food chain; and species highly susceptible to entrapment, impingement, entrainment or thermal discharge effects). Appraisals of the ecological assemblages present at intake and discharge areas and available habitats for selected important and representative species have been made. An assessment of potential or observed impacts on the marine ecology at each site is provided.

Data collected during a series of investigations covering the period August–October 1978 have been analyzed and compared with information previously reported from study sites in the same areas of Pearl Harbor. Plankton, epifauna, nekton, benthos and water column parameters have been sampled to provide the bases for ecological interpretation and evaluation. Generally, cooling water systems at three study sites produce only minor and localized impacts on the harbor ecosystem. Pearl Harbor contains a multifaceted estuarine ecosystem which has been significantly modified by human activities. Harbor biota have demonstrated a remarkable resiliency to various perturbations during the past fifty years. Present ecological conditions in Pearl Harbor represent a complex mixture of indigenous and exotic biota with varied responses to man-induced alterations, pollution stresses and recovery capabilities.

INTRODUCTION

BACKGROUND

The Environmental Protection Agency (EPA), under the provisions of Public Law 92-500 (The Federal Water Pollution Control Act Amendments of 1972) Section 316(b), requires that cooling water intake structures reflect the best technology available for minimizing adverse environmental impact. Section 316(a) refers to the effluent (discharge) limitations which must be met before a permit will be issued under the provisions of the National Pollutant Discharge Elimination System (NPDES) regulations. Administrative authority for the establishment of thermal discharge zones of mixing is now held by the Department of Health (DOH) under the provisions of Chapter 37-A of the Hawaii State Public Health Regulations.

At the request of the Naval Facilities Engineering Command, Pacific Division (Makalapa, Hawaii), the Naval Ocean Systems Center (NOSC), Hawaii Laboratory, submitted a proposal to perform a series of marine environmental studies in Pearl Harbor, Oahu. Specific study sites were identified as harbor marine environments adjacent to the intake and discharge structures for former power plant 2 (Pearl Harbor Naval Shipyard), former power plant 3 (Hospital Point near dry dock 4) and the discharge for the Submarine Training Center (Ford Island). The study was initiated in July 1978, with preliminary study activities (e.g., review of existing data, initial site visits, equipment fabrication, survey design, meetings with Hawaii Department of Health and Public Works Center, Pearl Harbor, representatives, etc.), and continued until October 1978.

STUDY SITES

The Utilities Division of the Public Works Center operates former power plant 2 (see figures 1 and 2), which is located in the controlled industrial area of the Pearl Harbor Naval Shipyard (PHNSY). Power generation in the facility ceased in May 1976, but the plant remains in continuous operation (i.e., 24 hours per day, 7 days a week), producing steam for shipyard use and distilling boiler feed water for shipboard use (figure 3).

Cooling water circulates through the plant via a conduit system with the primary intake structure located under pier B-1 and the heated effluent discharge structure about 125 metres east of the intake, between piers B-1 and B-2. Harbor water is drawn from 1.5 to 3.5 metres below the surface through a four-square-metre opening (figure 4). Cooling water and associated biota pass through two sets of screens prior to entering the plant: an outer trash screen of 38mm (1½-inch) mesh; and an inner, traveling screen of 9.7mm (3/8-inch) mesh. Heated effluent enters the harbor from a two-by-two-metre discharge opening with its vertical midpoint at the tidal datum of MLLW. The average cooling water flow rate for power plant 2 during the period October 1977–September 1978 was 39.0×10^6 litres per day (or 10.303 MGD; range: 9.386–10.486 MGD).

Former power plant 3 (building 177) is located near Hospital Point, adjacent to dry dock 4, PHNSY and operated by Public Works Center personnel on a continuous basis for the production of compressed air. Power generation was terminated at power plant 3 in December 1975. The cooling water intake structure (figure 5) draws water from 1.5–2.5 metres below the water surface through a downward-directed, rectangular concrete elbow

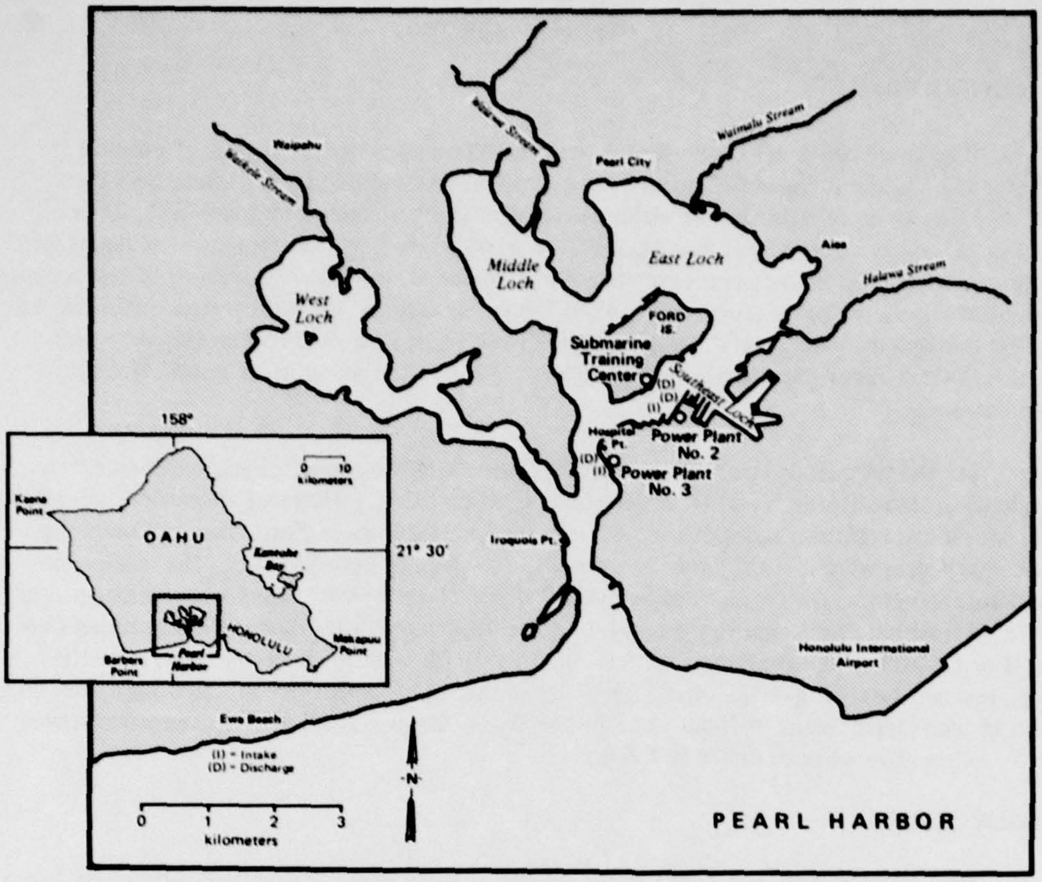


Figure 1. Study site locations, Pearl Harbor, Oahu, August-October 1978.

(with a four-square-metre opening) which extends about 15 metres from shore. Cooling water is drawn into the plant through an unscreened conduit system. Thermal effluent from power plant 3 enters the harbor about 125 metres northwest of the intake structure (figure 6). The concrete discharge structure has a rectangular opening (1.83 × 2.44 metres), situated at +0.5 to -1.3 metres relative to tidal datum (MLLW). The average cooling water flow rate from power plant 3 during the period October 1977–September 1978 was 0.57 × 10^6 litres per day (or 0.151 MGD; range: 0.113–0.119 MGD).

The Submarine Training Center on the southeastern end of Ford Island uses fresh water as a cooling medium for air conditioners and various training equipment and discharges the used water into Pearl Harbor. The facility is in operation approximately eight hours per day. Cooling water enters the harbor through a discharge structure located under the southwest end of pier F-1 (figure 7). Cooling water flow rates from this facility during the period October 1977 through September 1978 averaged 0.155 × 10^6 litres per day (or 0.041 MGD; range: 0.040–0.044 MGD).

Figure 2. Power plant 2 (building 149) located in the Pearl Harbor Naval Shipyard, southwest view.

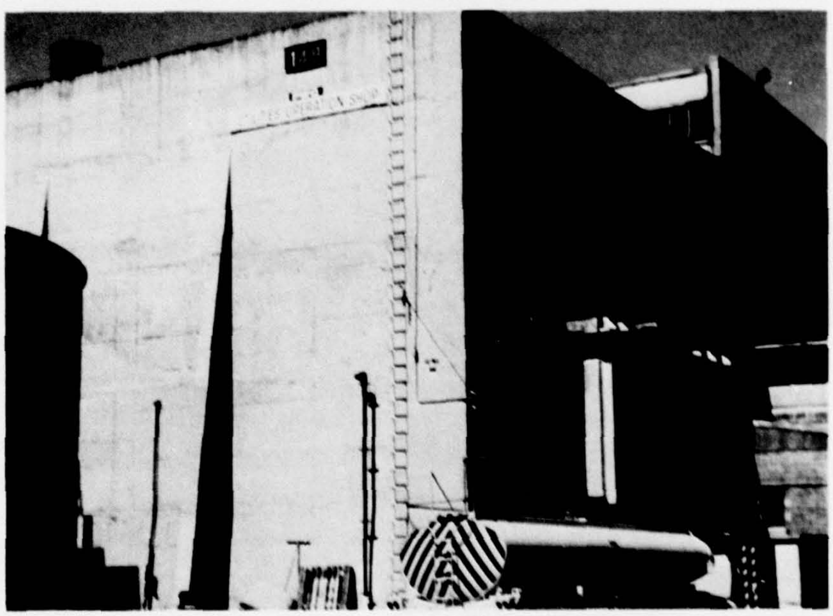


Figure 3. Power plant 2, from the south. The tank truck in the foreground carries boiler feed water from the plant for shipboard use.

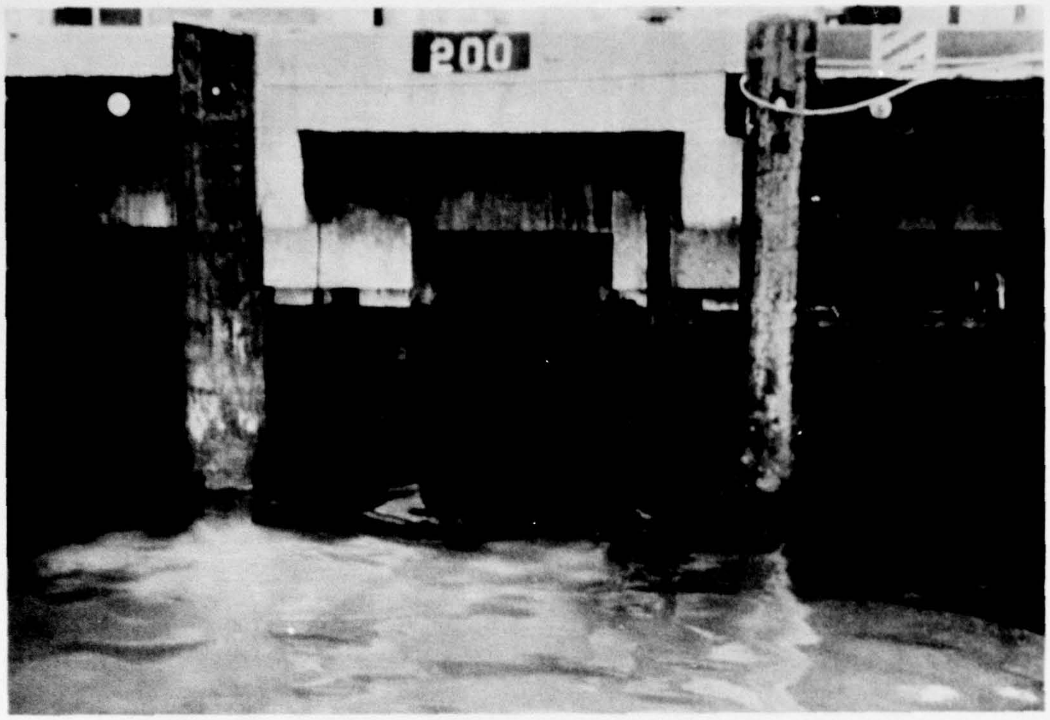


Figure 4. Cooling water intake structure at power plant 2, pier B-1, Pearl Harbor.

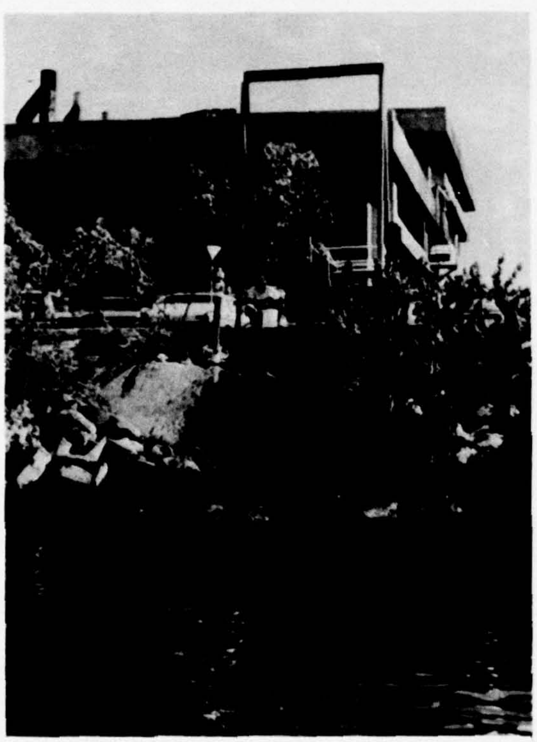


Figure 5. Power plant 3, intake structure (in foreground).

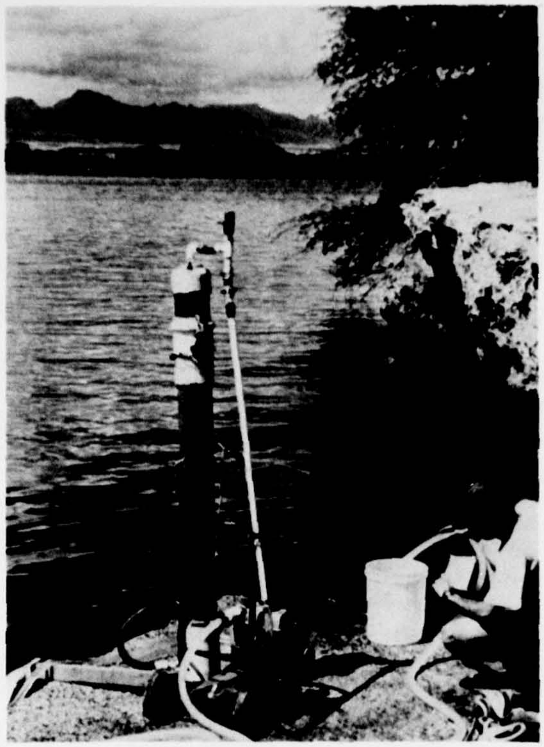


Figure 6. Discharge site for power plant 3 looking across entrance channel; Hospital Point is seen at right.

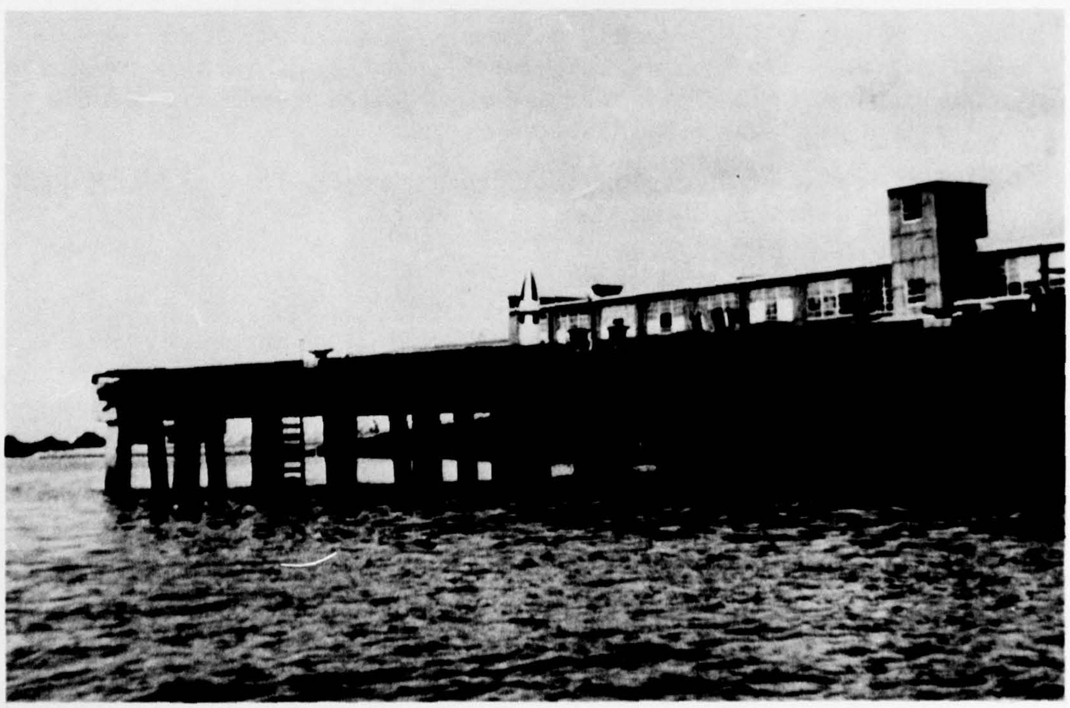


Figure 7. Pier F-1 covering the discharge structure for Submarine Training Center located on Ford Island; discharge is under the pier on right side of photo.

REVIEW OF EXISTING DATA

Data, procedures and analytical techniques from other environmental studies were reviewed prior to and during this investigation. The principal reference data sources include the following:

- NOSC environmental studies in Pearl Harbor from May 1971–August 1973, and November 1974–April 1977 (Evans, *et al.*, 1972; Peeling, Grovhoug and Evans, 1972; Evans, 1974; Grovhoug, 1976; Grovhoug and Rastetter, in preparation). Data from these studies were reexamined for comparison to results from this investigation.
- Naval Facilities Engineering Command, Pacific Division, studies in Pearl Harbor in 1976 (several letter reports to EPA) in which preliminary data were collected and reported for zone of mixing studies at power plants 2 and 3, and the Submarine Training Center, Ford Island. Intake structures at power plants 2 and 3 were also surveyed to determine any adverse environmental impact.
- Hawaiian Electric Company (HECo) conducted marine studies at the Waiau generating station in East Loch of Pearl Harbor (McCain, 1974). Plankton and larval fish investigations completed for HECo in 1973 describe harbor plankton patterns which are especially relevant to the present studies.
- HECo marine environmental investigations conducted at the Kahe Point generating station (McCain, 1977) also provided valuable insight to study design and analytical considerations.
- The proceedings of three national power plant entrainment and impingement workshops (Jensen, 1974; Jensen, 1976; Jensen, 1978) were reviewed at the outset of this investigation. These workshops were sponsored by the Electric Power Research Institute (EPRI) and provided valuable and up-to-date information concerning environmental study techniques at power plants.

Numerous other references were utilized during this study. These are cited at appropriate locations in the text and are fully listed in the references.

APPROACH

Potential impacts at intake structures which may affect the harbor ecosystem include pumped entrainment, impingement and entrapment. Entrainment refers to the incorporation of organisms into the cooling water flow. Pumped entrainment occurs when those organisms that enter the intake are pumped through the condensers. Within the plant entrained organisms may experience various mechanical, pressure, thermal and chemical effects. Plume entrainment refers to the incorporation of organisms into the discharge plume by effluent flow phenomena. The terms impingement and entrapment pertain to the physical blocking of larger motile organisms by a barrier, usually some type of screening device in cooling water intake systems. Impingement emphasizes the physical contact of organisms with part of the intake structure, while entrapment refers to the prevention of escape from intake areas, often due to physical (intake configuration) or functional (e.g. high flow rate) attributes. Impingement and entrapment at traveling screen sites have potentially adverse effects on certain nekton and macroinvertebrate fauna. Therefore, part of this study was dedicated to the evaluation of impingement and entrapment effects on the marine ecosystem adjacent to power plant 2. This was the only study site where intake screening devices were present during this investigation.

Discharge structures represent potential sites for adverse environmental effects due to various thermal, chemical or flow-related characteristics. Plume entrainment, disturbance of indigenous community structure, exclusion of important biota from a region, severe productivity alterations or mortality to specific organisms (i.e. fish kills) all exemplify potentially adverse effects at cooling water discharge sites.

Habitat formers are described in an EPA 316(b) draft Guidance Document for Evaluating the Impact of Intake Structures on the Aquatic Environment (1977), as those flora and fauna characterized by a relatively sessile life state with aggregated distribution which function as: 1) a live and/or formerly living substrate for the attachment of epibiota; 2) either direct or indirect food source for the production of shellfish, fish and wildlife; 3) a biological mechanism for the stabilization and modification of sediments contributing to the process of soil building; 4) a nutrient recycling trap or pathway; or 5) specific sites for spawning and providing nursery, feeding and cover areas for fish and shellfish. Marine fouling organisms, i.e. those biota growing attached to submerged man-made structures such as ship hulls, pilings, cooling water piping systems, etc., are a major category of habitat formers. Many fouling species are obvious nuisance organisms, especially in maritime harbor environments such as Pearl Harbor.

This study was undertaken to provide reliable information about the condition of marine biota at specific locations in Pearl Harbor. Sampling efforts were directed toward the collection of quantifiable data that provide a realistic appraisal of harbor ecosystems adjacent to intake and discharge areas. Intensive field sampling started in August and continued through the end of October 1978. Field observations and collections focused on representative components of the harbor ecosystem at each study site; specifically, those biota which are representative in terms of 1) a balanced indigenous harbor community, 2) commercial or recreational value, 3) species status, i.e. rare, threatened or endangered, 4) nuisance species, 5) critical relationships to the structure and/or function of the ecosystem, such as habitat formers, 6) importance in the food cycle, and 7) susceptibility to entrainment, impingement, entrapment or thermal discharge effects. Representative taxa from the planktonic, nektonic, benthic and epifaunal components of the Pearl Harbor marine community were identified, selected and evaluated in terms of existing environmental conditions within the study regions.

Marine environmental data were collected at study sites during an integrated and combined sampling program. Certain field activities such as plankton tows and dye studies yielded data relevant to both intake and zone of mixing (discharge) evaluations. Since various organisms or life stages are differentially susceptible to damage from cooling water systems, nearly twenty representative taxa were selected for closer examination. Although separate effects were measured, identified and evaluated, a broad ecosystem approach has been followed in the design and execution of this study.

An attempt has been made throughout this report to provide data in sufficient detail to allow further analysis and evaluation by the reader. Study site descriptions, geographic coordinates and sampling activities are summarized in table 1. Detailed descriptions of equipment and methods used during this study are presented next. Data presentation and results of individual sampling activities used at each site precede the final discussion, where

Table 1. Study site designation, location, sampling activities and brief description of area, Pearl Harbor Study, August–October 1978

Site	*I/D	**Lat/Long	***Activity	Description
Power plant 2 (PHNSY)	I	21°21'22.6"N 157°57'35.0"W	FT/IM/OB/ PF/PT/WQ	Under pier B-1 @ 200' marker; water depth: 7.6m; silt and rubble
Power plant 2 (PHNSY)	D	21°21'25.3"N 157°57'33.0"W	BC/FP/FT/OB/ PT/TM/WM/WQ	Under pier between B-1 and B-2 @ 600' marker; water depth: 7.6m; silt and rubble
Power plant 3	I	21°20'57.2"N 157°58'10.9"W	FT/FP/OB/PF PT/TM/WM/WQ	20m north of Oscar pier; water depth: 2m sloping to 10m; rock ledge to silt
Power plant 3	D	21°21'0.5"N 157°58'13.8"W	BC/FT/OB/ PT/TM/WQ	SW shoreline, Hospital Pt.; water depth: 2m sloping to 15m; debris and silt
Submarine Training Center (Ford Island)	D	21°21'35.2"N 157°57'49.8"W	BC/FP/FT/OB PT/TM/WQ	Under pier F-1; water depth: 1.5m sloping to 7m; hard bottom to silt

Legend: *I/D = Intake/Discharge; **Lat/Long = Latitude/Longitude; ***Activity – BC = Benthos Collection, FP = Fouling Panels, FT = Fish Traps, IM = Impingement Collections, OB = Diving Observations, PF = Plankton Filter-pump Sampling, PT = Plankton Tow Net Sampling, TM = Temperature Data, WM = Water Motion (Clod-cards), WQ = Water Quality Data (including Dye Studies).

evaluations of intake and zone of mixing effects are provided. A comparison of impact on existing assemblages at each site within the harbor completes the discussion and conclusions section.

METHODS

ENTRAINMENT

The plankton resident in harbor waters are the source for most planktonic biota near or in cooling water structures. In Pearl Harbor, however, not all species are found nearshore due to different responses to the combined effects of shading, water motion, subsurface intake configurations and various other physical characteristics of cooling water structures. To compensate for these potential variations, two types of collections were made: 1) net tows to evaluate the plankton populations in harbor open water (far field) areas, and 2) filter-pump collections to evaluate the planktonic components actually entrained in the cooling water systems.

Harbor waters adjacent to study sites were sampled using a 0.5-metre-diameter, 243-micron-mesh (Nitex) plankton net with a simple conical configuration and a 5:1 length-to-diameter ratio. A towing interval of three minutes was selected after trial runs indicated that net clogging from phytoplankton might occur for longer duration tows. Triplicate subsurface tows (1.5 metres beneath the water surface) were made. The net was towed 20 metres behind an outboard-powered skiff at a speed of about 1.0 knots (0.5 metre per second). Each towing interval was precisely timed using a stop-watch. All plankton tows were metered using an eccentrically mounted General Oceanics (Model 2030-R2) oil-filled, digital flow meter (figure 8). At the completion of each tow, the sample was thoroughly washed into the cod end collection bucket (figures 9 and 10) and transferred to a clean, one-litre screw cap container.

Plankton collections were also obtained using a filter-pump system similar in design to that described by Icanberry and Richardson (1973). The basic filter-pump sampler used during this study was loaned to NOSC by Dr. John C. McCain and Dr. Stephen L. Coles, Environmental Department, Hawaiian Electric Company, Honolulu. Structural and design modifications were made to enable sample collection from cooling water structures at the power plant sites under investigation. During each filter-pump collection period, water was sampled from one metre below the surface for 30 minutes duration. Both volumes and flow rates were dependent on suction head which varied from 0.3 to 5 metres at collection sites. Flow rates were determined at three-minute intervals by measuring the volume discharged into a graduated container during 15- or 30-second periods (figure 11). The filter-pump sampler collected plankton from cooling water within the conduit structures which could not otherwise be sampled by conventional tow netting techniques (figure 12). Water is pumped up through a 20mm-diameter intake hose into a 1.5-metre-high column containing a 215-micron-mesh net and removable bucket prior to passing through the water pump (figure 13). The pump was powered by a 2-cycle, 52.5cc gasoline engine. Zooplankters are filtered from the water before entering the pump, where they would potentially experience mechanical or pressure-related damage. The column, pump and engine have been mounted on a lightweight, two-wheeled dolly for added mobility and convenience (figure 14). A detailed description of the design, construction and operation of this filter-pump sampling system is available upon request from the author.

Using a modification of the techniques described by Dressel *et al.* (1972) and Crippen and Perrier (1974), all plankton samples were stained *intra vitam* using neutral red, a vital stain and basic dye (at a final concentration of 1:100,000 for one hour) prior to fixation in 5-percent seawater-formalin. A vital stain is a non-toxic dye which stains only living cells and greatly facilitates live:dead determinations for most planktonic organisms. This technique has recently been used in several zooplankton entrainment and mortality studies (Carpenter *et al.*, 1974; Heinle, 1976; McCain, 1977). Preserved samples were placed in an ice cooler in the field immediately after preservation and kept refrigerated (at about 5°C) to increase color retention until laboratory analyses began.

Laboratory analyses for all plankton samples were conducted in several stages. Standard zooplankton laboratory techniques were used to determine settled volume, species identification and enumeration. Initially, samples were allowed to settle overnight in either 15ml glass settling tubes (for smaller volume filter-pump samples) or in graduated cylinders (for the larger volume tow net samples). Next, the entire filter-pump samples were sorted into major taxonomic groups. Because the tow net samples consisted of much larger volumes and very dense diatom concentrations, 1/128th aliquots were withdrawn using a Folsom splitter. All organisms from these aliquots were sorted into major taxa. Observations of live:dead ratios were recorded for selected groups at this time. Final analysis consisted of specific

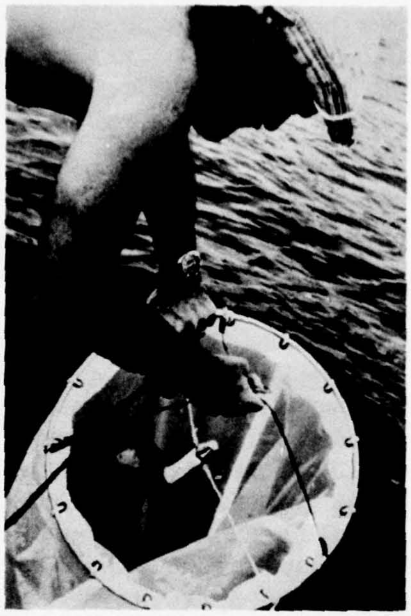


Figure 8. Zooplankton net with eccentrically mounted digital flow meter.

Figure 9. Zooplankton net with collection bucket at cod end.

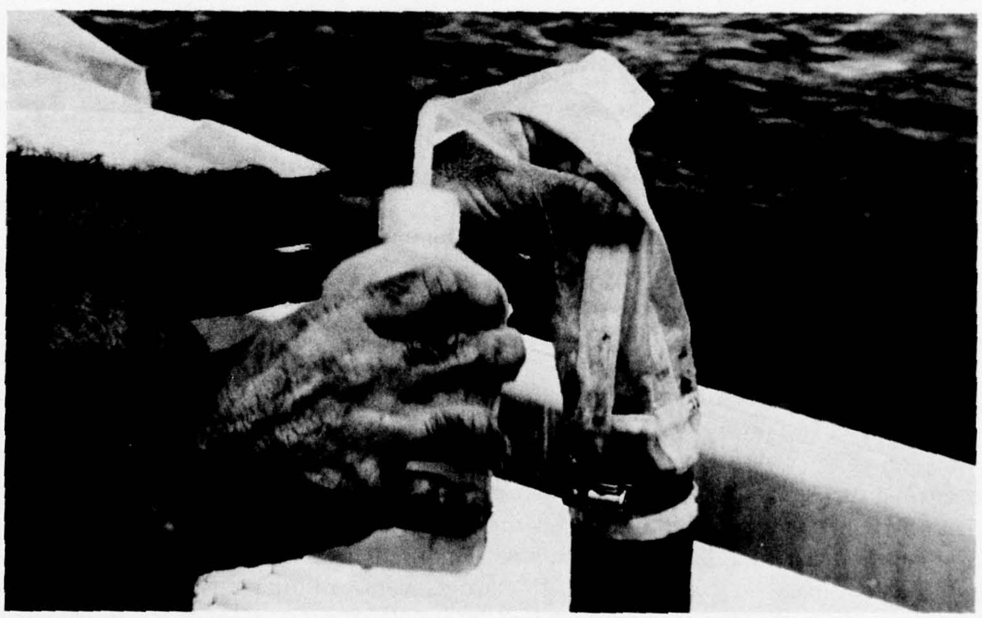


Figure 10. Washing down a zooplankton sample into the cod end bucket.

Figure 11. Flow rate determination during a filter-pump collection at power plant 3 discharge.

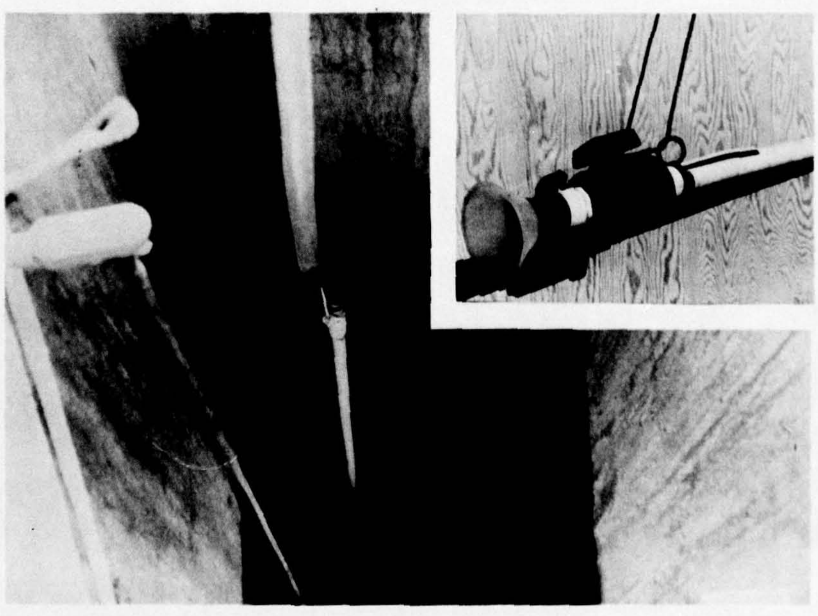


Figure 12. Power plant 3 intake access port used for zooplankton filter-pump sampling (inset). Distal end of inlet tubing and valve used in priming the filter-pump.

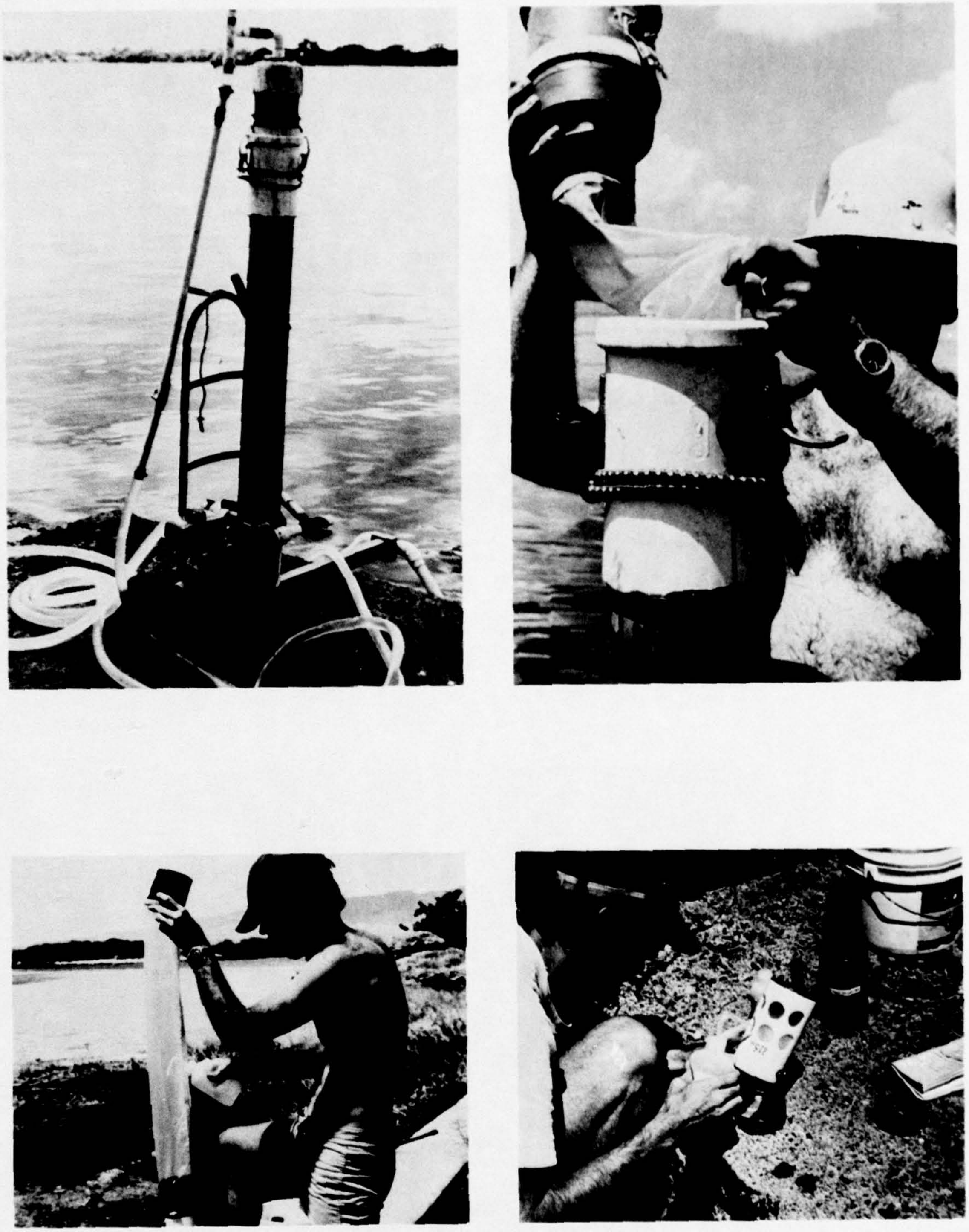


Figure 13. Composite of various stages in filter-pump sampling: a – operating filter-pump apparatus, b – removing plankton net from cylinder, c – washing sample down into cod end collection bucket and d – rinsing sample into sample jar.

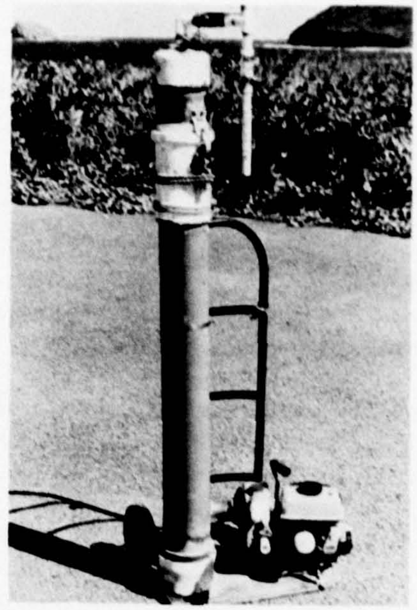


Figure 14. Filter-pump sampler mounted on two-wheeled cart, hoses removed.

identifications for dominant taxa and a detailed analysis of most holoplanktonic and meroplanktonic larval stages. Further observations concerning live:dead determinations were also provided. For numerically abundant groups such as barnacle nauplii, molluscan veliger larvae and chaetognaths present in some samples, aliquots of one-half or one-quarter of the original volume were taken using a Folsom splitter. All enumerative data for planktonic biota in this report are recorded as number of individuals per cubic metre. Preliminary examination of phytoplankton composition data for the tow net samples was performed using a hemocytometer and percent composition for major algal genera was estimated.

Statistical analyses of plankton data were performed using the University of Hawaii Computing Center's Hewlett Packard 2000 Computer. Taxa were selected based on their concurrent abundance in both filter-pump and tow samples for the most numerically dominant taxa within these groups. To test the effects of through-plant transit on entrained zooplankton, numerically abundant categories were compared to determine the number of individuals in a category from intake vs. discharge samples taken on the same day. A one-tailed, paired t-test was used on the assumption that no plant-related effects could increase the number of organisms found in the discharge samples. Tests for significance at the 1-percent and 5-percent levels were made.

IMPINGEMENT/ENTRAPMENT

Presurvey field sampling design yielded a technique for quantitative impingement sample collection. Diving and above water observations by the survey team and interviews with power plant personnel provided additional information concerning entrapment.

Impingement samples were collected at the traveling screen site of power plant 2 located inside building 149A (figure 15). A 305 × 480mm wooden frame supporting 6mm-square-mesh galvanized hardware cloth containing a fine nylon screen (1.5mm mesh) insert (figure 16) was placed in the traveling screen sluiceway during 30-minute sampling intervals. The traveling screen was operated only once daily (during sample collection) to facilitate maximum collection of impinged organisms. Material collected on the 1.5mm mesh screen was preserved *in toto* at the collection site in a one-litre screw-cap bottle containing 10-percent seawater-formalin. The procedure consisted of removing all biota from the screen and sample container, transfer to 70-percent isopropyl alcohol and separation into major taxonomic groups. These organisms were further sorted and identified to the most specific level possible. Laboratory data sheets contain an enumeration of individuals by taxa for each collection.

Qualitative observations were made to estimate potential entrapment at the intake tunnel and traveling screen access port. Discussions with Public Works Center, Pearl Harbor, personnel yielded some anecdotal information concerning entrapment and impingement.

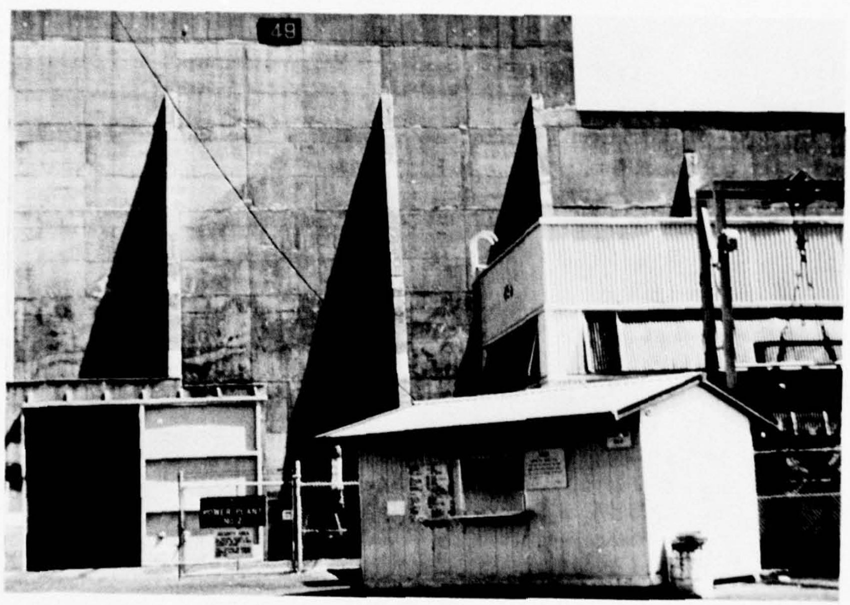


Figure 15. Screen house (on right side of photo) at power plant 2; at this site, plant personnel use the A-frame for raising large mesh screens; traveling screen is located inside the building behind A-frame.

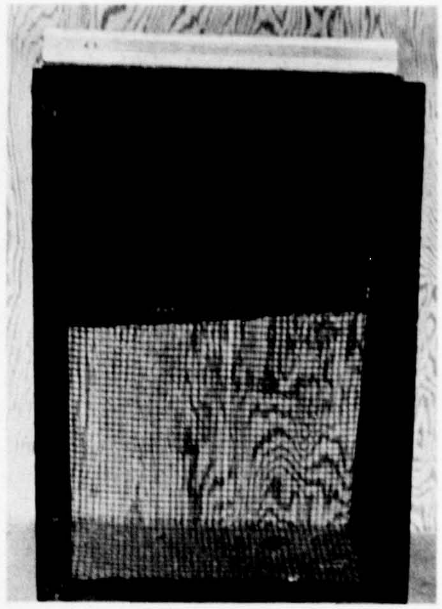


Figure 16. Impingement sampling frame and 1.5mm mesh insert.

HABITAT FORMERS

Part of the field efforts during this investigation were directed toward an evaluation of the impact from intake and discharge structures on marine fouling biota inhabiting the primary study area. Underwater diving observations of fauna attached to pilings provided qualitative information for longer-term colonization patterns. Shorter-term fouling panel exposures provided quantitative data describing settlement patterns for fouling biota (habitat formers) during this study.

Each fouling panel array consisted of six, 150 X 150mm removable panels (three PVC and three asbestos flexboard) attached to a 660 X 200 X 3mm plexiglass backing plate using nylon bolts. These arrays (figure 17) were suspended vertically at one-metre depths using surface floats and weights on the bottom to provide stability during conditions of high water motion. All arrays were positioned between pilings under covered wharfs (figure 18) and only exposed to indirect sunlight. These arrays were also used as attachment sites for clod-cards (a newly-developed modification of the technique for measuring integrated water motion during an interval of several days; Muus, 1968; Doty, 1971) and maximum-minimum thermometers (figure 19). Fouling panel arrays were usually exposed for two-week intervals to provide larval settlement and colonization data at study sites. At the Ford Island site, the initial settlement period was extended to three weeks because of logistics problems.

Fouling panel arrays were retrieved from the field after pertinent observations had been recorded. Panels were detached from the plexiglass backing plates and transported to the laboratory in zip-lock plastic bags containing fresh seawater. Laboratory photographs were taken of each panel using a Nikon F, SLR, camera (with a 55mm Macro-Nikkor lens).

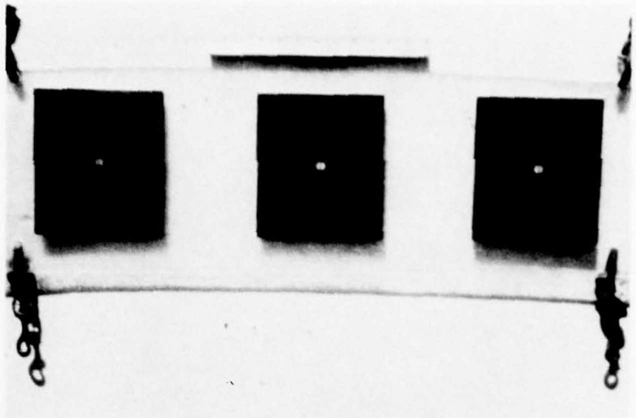


Figure 17. Typical fouling panel array, similar to that used during this study, showing three PVC fouling panels.

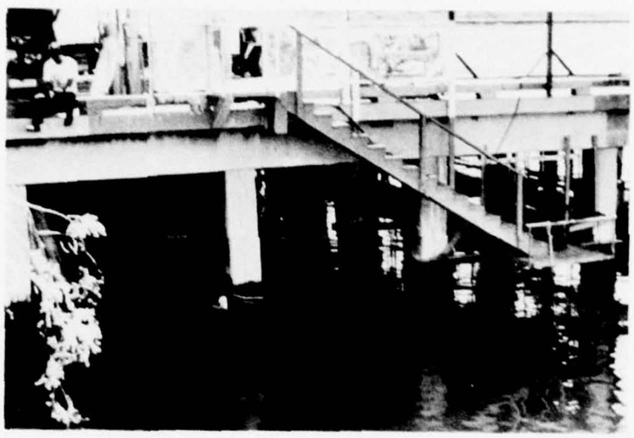


Figure 18. Fouling panel array site at power plant 3 intake area.

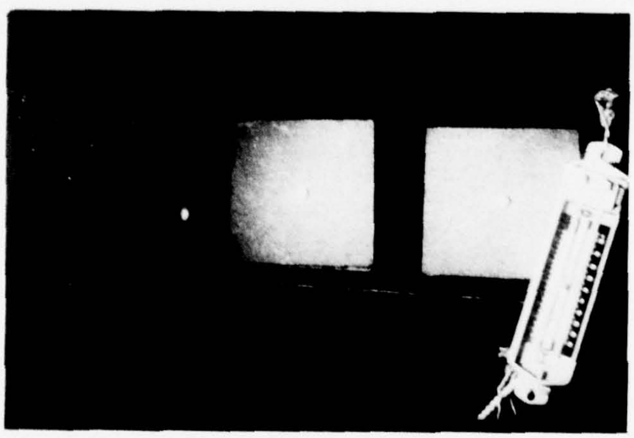


Figure 19. Underwater photograph of fouling panel array at power plant 2, showing max-min thermometer attached.

Adequate light was provided by two Honeywell Model 202 strobe lights. Projected slides were viewed to provide detailed aspects of living panel biota which facilitated identifications where color and growth patterns are diagnostic. Photographic documentation serves as a permanent, readily maintained record available for future analyses, comparisons or evaluations. After photographs were taken in the laboratory, panels were fixed for several days in 10-percent seawater-formalin prior to transfer to 70-percent isopropyl alcohol. Fouling biota were examined using a variable power (1X–7X) binocular dissecting microscope. Grid count analyses were performed to provide frequency determinations of common fouling taxa (figure 20). Frequency is a measure of the probability of encountering a particular taxa in a certain size quadrat. One hundred 5 × 5mm quadrats were etched in a regular grid pattern on a 150 × 150mm plexiglass overlay. Using this overlay to analyze each panel, frequencies of occurrence were recorded for each taxa encountered. For example, if one or more barnacles were present in 45 of the one hundred quadrats, this taxa received a frequency of 45 percent. An organism was recorded "present" if any part of the animal overlapped into the quadrat. These data were obtained for three replicate panels of each material (PVC and asbestos) at each location during each exposure period. Various numerical analyses were performed to: examine biotic variability among replicate panels on the same array, compare PVC vs. asbestos colonization rates and evaluate epifaunal distribution between various study sites and exposure intervals. Analysis concentrated on the success of the different species at two locations, power plants 2 and 3. Since two substrata (PVC and asbestos) were used, the data were treated in a two-way analysis of variance (ANOVA) on arcsine transformations of frequency data using the program ANVAR4 on the University of Hawaii Computing Center's Hewlett Packard 2000 computer. The data were also compared with prior observations at other sites in Pearl Harbor (Grovhoug, 1976), to evaluate possible impact attributable to intake and discharge structures during the present study.

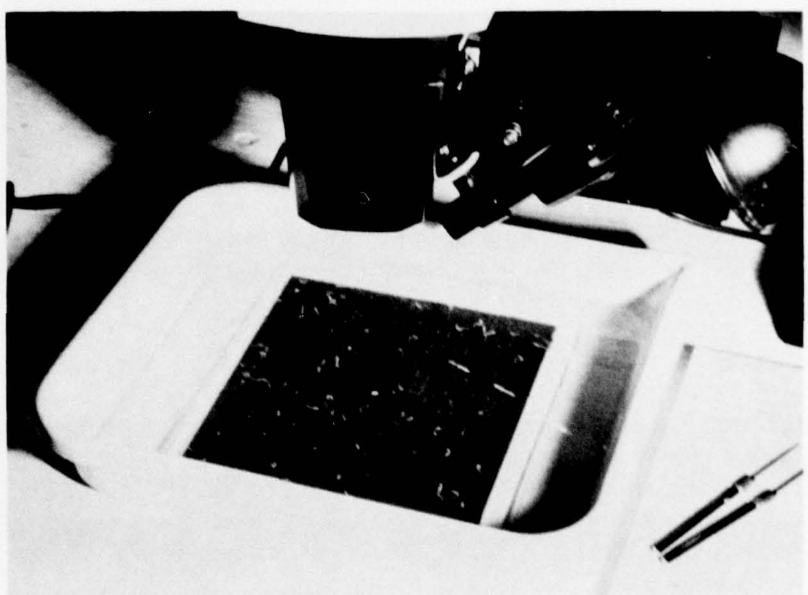


Figure 20. Laboratory apparatus for conducting grid analyses for fouling panel biota.

NEKTON

Various free-swimming fishes and macroinvertebrates inhabit Pearl Harbor marine environments adjacent to former U. S. Navy power plant intake and discharge structures. During this study, fish trap collections and nontransect underwater observations were made to assess qualitatively the influence of shore-based cooling water systems on nektonic harbor biota. Due to the motility exhibited by most nektonic forms and the recognized selectivity of nearly all fish sampling techniques (Allen *et al.*, 1960), the present study also utilizes results from previous studies in Pearl Harbor (Evans, 1974). Fish transects were not used because of turbid water conditions. Other techniques of nekton census such as netting, poisoning or spearing were not used.

Funnel entrance fish traps were set at intake and discharge study areas. Each trap measured 1 X 1 X 0.5 metres and was constructed of a 5mm-diameter metal rod frame covered by a 25mm (1-inch) mesh, medium gauge poultry wire. Access into the trap was available through a hinged 0.45 X 0.35-metre door located in the end opposite the funnel entrance. Traps were set for about three days prior to retrieval during several trapping series at each site. Fish and macroinvertebrates were removed from the traps using a fine mesh dipnet. Upon removal from the trap, organisms were identified, measured, enumerated and either released or retained for further analysis.

Qualitative underwater observations were recorded throughout the study for comparison with previous observations and data. Anecdotal information was obtained from PWC personnel. Nektonic components in the vicinity of study sites were monitored rather than intensively sampled during this investigation. Reliance on previously collected data seemed appropriate within the time constraints of this study.

BENTHOS

Benthic infaunal biota were sampled using a one-litre scoop sampler, shown in figure 21. Three replicate benthos collections were made at each discharge study site. Reliance on previously collected infaunal harbor data (Evans, 1974) obviated the need for extensive benthos collections during this study. Infaunal communities have more stable, homogeneous populations than planktonic or epifaunal communities (Lie and Kelley, 1970; Peterson, 1977; Thorson, 1957). Sample collection during this investigation provides sufficient information to evaluate benthic community status at these sites when compared with previously collected harbor data.

The benthos scoop sampler was constructed of a 150mm X 90mm inside diameter PVC cylinder fitted with a handle and plexiglass cover plate (figure 22). Infaunal samples were collected from harbor sediments at 6- to 7.5-metre water depths. A SCUBA-equipped diver collected samples by descending to the bottom, rotating the sampler down through the sediment-water interface in a scooping motion and attaching the cover plate onto the open end to prevent sample loss during ascent. Upon reaching the surface, the contents of the scoop sampler were transferred to a 300 X 300mm plastic, zip-lock bag and fixed in a 10-percent seawater-formalin.

Samples were sieved and rinsed with tapwater through a graded series of screens (4mm, 2mm, 1mm, and .5mm mesh) to remove larger rubble and fine silt. Material retained

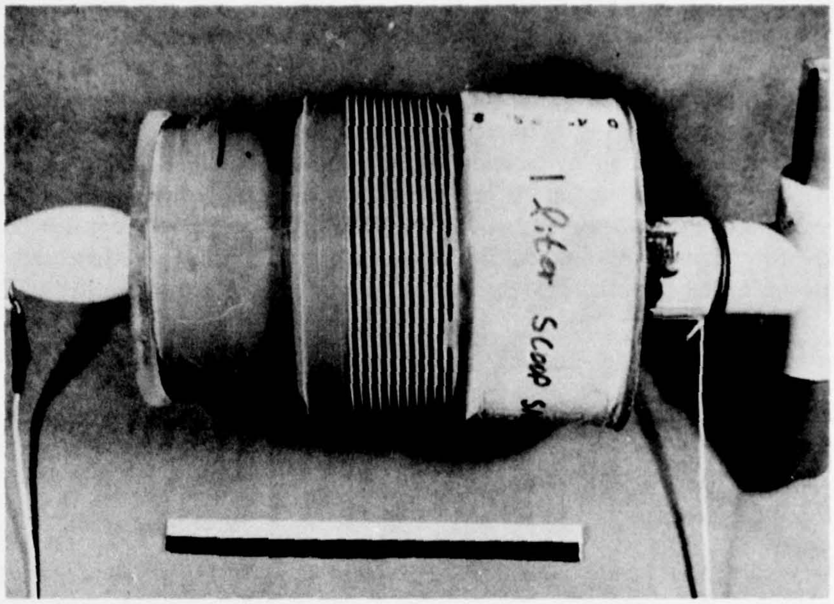


Figure 21. Benthos scoop sampler.

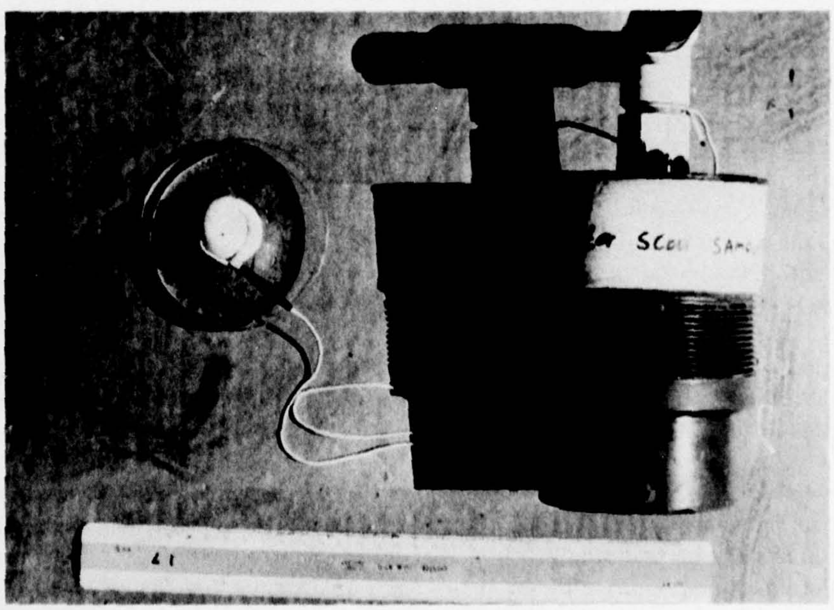


Figure 22. Scoop sampler with end cap (left) removed.

on the 1mm and larger screens was examined using an illuminated magnifier. All organisms were sorted from non-living debris in these samples. Material retained on the .5mm screen was transferred to 70-percent isopropyl alcohol for further examination using a binocular dissecting microscope. Material passing the .5mm screen was dried for grain size analysis (not reported here). After screening, one of the replicate samples from each station was processed using a nitric acid bath which dissolved all calcium carbonate components in the sample, reduced the volume to be sorted and provided a check on the thoroughness of sorting efficiency for the undissolved samples (Brock and Brock, 1977). However, the acid dissolution technique removes many diagnostic characteristics (such as shells, tubes, spicules of some sponges, etc.) from some benthic taxa, and, therefore, the other two samples from each station were examined in a preserved, intact condition. The material from the .5mm screen was sorted into various taxonomic categories and enumerated on laboratory record sheets. Selected groups have been further identified to the family, generic or specific level.

WATER COLUMN

Water column characteristics such as temperature, water motion and discharge plume phenomena are relevant to the evaluation of cooling water impacts on marine ecosystems (Cannon and Lauer, 1976; Coutant, 1970; Coutant, 1972) and were measured during this study.

Temperature data were collected using a Yellow Springs Instruments (YSI) telethermometer (Model 42SC) (figure 23) equipped with a three-metre sampling probe extension. Discrete temperature data were recorded from intake and discharge areas during each plankton sampling operation. Additionally, temperature was profiled during other periodic site visits and further temperature data were collected during dye studies. Taylor (model 5458) maximum-minimum thermometers were emplaced at discharge areas (one-metre depths) and also attached to fouling panel arrays throughout the study. Maximum-minimum temperature ranges collected over three- to five-day increments provide useful information for power plant environmental studies (Grovhoug, 1978). All temperature data were recorded to the nearest 0.2°C.

Water motion was measured at selected study sites using a newly developed modification of the clod-card techniques described by Doty (1971) and Muus (1968). A value for water motion (in cm/sec) integrated over a five day period was obtained from the dissolution and attendant weight loss of cropped pyramidal blocks (see figure 24) constructed of carpenters fixall and plastic resin glue (for further details on this method, see Grovhoug, 1978, appendix A). Backing supports for the clod-cards were constructed of 45 X 90 X 3mm grey PVC strips rather than masonite, which has been previously tested (Grovhoug, 1978). Three replicate clod-cards were exposed for periods of approximately five days during each measurement period (figure 25). Clod-card triads were attached to fouling panel arrays at one-metre depths during this investigation.

Dye studies using fluorescein "sea marker" were performed at all study sites to 1) measure cooling water travel intervals, 2) provide a "tracer" for effluent water thermal characteristics and 3) evaluate discharge plume behavior. Approximately 250 ml of dry fluorescein powder contained in a fine mesh cotton bag was suspended at the entrance of intake conduits at each intake study site. Fluorescein dye is orange when dry, but changes to a brilliant chartreuse green when exposed to water. A stopwatch was used to time the interval

Figure 23. Recording temperature profile data at power plant 3 discharge.

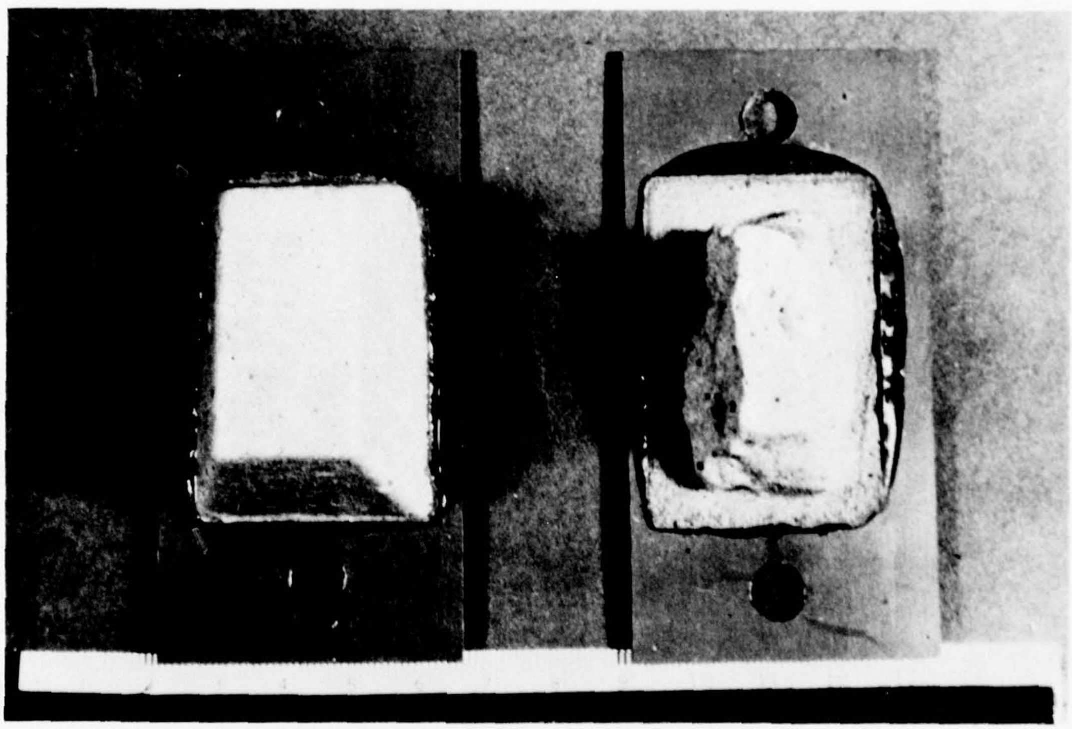


Figure 24. Clod-cards used for integrated water motion measurements; card at left is shown prior to exposure and card on right is shown after five days exposure.

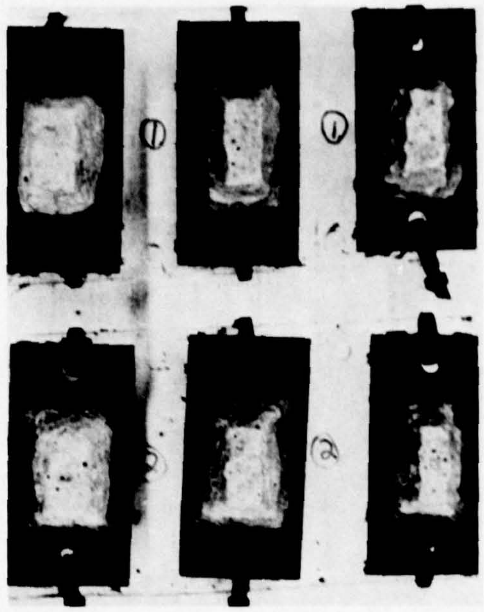


Figure 25. Visual display of replicate clod-cards showing very similar dissolution rates (see table 17 for actual weights).

from injection into the cooling water system until dye was observed in the discharge plume. These studies provided a measurement of cooling water residence time during average plant operating conditions.

Discharge plume characteristics were observed during the dye studies. Using a 13-foot outboard-powered skiff, field team members closely monitored the distribution of dye (both horizontally and vertically) within the harbor. Profiles at half-metre depth intervals were recorded until the dye dissipated. Dye studies were performed during typical trade-wind conditions.

RESULTS

GENERAL

The results of specific sampling activities are presented in a sequence corresponding to that for the description of methods. Data collection, interpretation, and presentation of results have been structured to characterize descriptive marine environmental parameters observed during the study. Selected representative important biota are discussed in appendix A. A cumulative checklist of all organisms identified during this investigation is presented as appendix B. This list contains approximately 175 taxa.

Voucher specimens or photographic records are maintained at the NOSC Hawaii Sample Processing Center for samples collected during this investigation. Numerical and taxonomic data collected are being verified and entered into the Hawaiian Coastal Zone Data Bank for future reference and manipulation, as desired.

ENTRAINMENT

Vital staining of zooplankton was employed during this investigation to determine live:dead ratios. This technique was moderately successful although harpacticoid copepods and *Lucifer* larvae did not stain well, even when obviously alive. However, these two groups comprised a minor proportion of the total zooplankters sampled. Dead forms of most taxa were present in net tow collections as well as both intake and discharge filter-pump samples and live:dead ratios provided an indication of within plant mortality to zooplankton during the study period.

Results from zooplankton tows are summarized in table 2. Time of day, lunar and tidal conditions were nearly identical during the two collection periods. As shown in table 3, plankton concentrations were about four times as dense in the 28 September 78 collections as they were on 26 October 78. Volumes of water filtered during three-minute tows ranged from 4.69 to 15.57 cubic metres (mean = 10.93, s = 3.56) depending upon wind and current conditions.

Table 2. Plankton tow by haul series, Pearl Harbor Study, August–October 1978

Tow #	*Site	**Time/Date	RST (m/sec)	Vol. water filtered (m^3)	Settled Volume (ml)	Conditions (Incoming)
A-1	PP3(I/D)	1047/28 Sep 78	.150	8.52	335	Hi @ 1350 (+.5m)
A-2	PP3(I/D)	1103/28 Sep 78	.215	7.45	425	Hi @ 1350 (+.5m)
A-3	PP3(I/D)	1111/28 Sep 78	.120	4.69	440	Hi @ 1350 (+.5m)
B-1	PP2(D)	1234/28 Sep 78	.230	7.95	158	Hi @ 1350 (+.5m)
B-2	PP2(D)	1249/28 Sep 78	.190	6.57	264	Hi @ 1350 (+.5m)
B-3	PP2(D)	1300/28 Sep 78	.210	7.21	285	Hi @ 1350 (+.5m)
C-1	PP2(I)	1025/26 Oct 78	.438	15.57	116	Hi @ 1245 (+.5m)
C-2	PP2(I)	1036/26 Oct 78	.432	15.10	70	Hi @ 1245 (+.5m)
C-3	PP2(I)	1045/26 Oct 78	.418	14.77	132	Hi @ 1245 (+.5m)
D-1	STC(D)	1100/26 Oct 78	.340	12.06	104	Hi @ 1245 (+.5m)
D-2	STC(D)	1131/26 Oct 78	.411	14.60	153	Hi @ 1245 (+.5m)
D-3	STC(D)	1145/26 Oct 78	.379	12.55	98	Hi @ 1245 (+.5m)
E-1	PP3(I/D)	1154/26 Oct 78	.383	12.93	145	Hi @ 1245 (+.5m)
E-2	PP3(I/D)	1203/26 Oct 78	.381	12.78	165	Hi @ 1245 (+.5m)
E-3	PP3(I/D)	1213/26 Oct 78	.318	11.22	190	Hi @ 1245 (+.5m)

Legend: *Sites – PP3 = power plant 3, PP2 = power plant 2, STC = Submarine Training Center (Ford Island), (I) = Intake, (D) = Discharge, (I/D) = Intake/Discharge; **Time/Date = times listed are starting times for 3 minute towing intervals; RST = relative speed of tow (from flow meter calculations), reflecting the net speed through the water.

Table 3. Condensed plankton tow data, Pearl Harbor Study, August–October 1978. Mean values for each series, calculated from three replicate tows per site from data in table 2. Standard deviations are in parentheses

Series	Site	Date	Vol. Filtered (m^3)	Settled Vol. (ml)	Settled Vol. (ml/m^3)
A	PP3	28 Sep 78	6.89 (1.98)	400.00 (56.79)	58.06
E	PP3	26 Oct 78	12.37 (0.95)	166.67 (22.55)	13.54
B	PP2	28 Sep 78	7.24 (0.64)	235.67 (68.08)	32.55
C	PP2	26 Oct 78	15.15 (0.40)	106.00 (32.19)	7.00
D	STC	26 Oct 78	13.07 (1.35)	166.67 (22.55)	12.75

Common zooplankton taxa collected in net tows are listed in table 4. Laboratory analyses have provided numerical data for 21 planktonic taxa resident in the study regions of Pearl Harbor. Figure 26 presents composition data for major zooplankton taxa collected in net tows from data assembled by combining all tows at a station and calculating percent composition of the total from individuals in a given category. The microcopepods, *Acrocalanus inermis* and *Oithona simplex*, were numerically dominant in zooplankton tow net samples. Holoplanktonic carnivores, such as *Sagitta enflata*, were consistently represented in all zooplankton net collections. Jellyfish (probably *Phyllorhiza punctata*, as described and pictured in Devaney and Eldredge, 1977) which are seasonally abundant during October–November in Pearl Harbor, were not collected or observed during tow net sampling. A single specimen was collected by hand adjacent to the discharge for power plant 2 during the study.

Discrete zooplankton samples were collected at intake and discharge structures at power plants 2 and 3. Data from the 33 filter-pump samples are summarized in table 5. The filter-pump sampling system performed reliably during the sampling periods and maintained remarkably similar flow rates and volumes of water filtered at intake and discharge structures (table 6). Volumes of water filtered varied from 0.7 to 1.5 cubic metres (mean = 1.04, s = 0.23) during each sampling period; flow rates varied from 23.75 to 51.10 litres per minute (mean = 34.77, s = 7.80). Table 7 provides a listing and indication of relative abundance for planktonic taxa identified from filter-pump collections. Many living zooplankton were observed from discharge samples, indicating that mortality is considerably less than total at any site. Percent composition data for major zooplankton taxa are presented in figure 27. These data were calculated by combining all filter-pump collections at site (intake and discharge collections were handled separately) and dividing the number of individuals per taxa by the total numbers sampled at the site to obtain the percent composition given. Although entrainment mortality is greater at power plant 2 than at power plant 3, neither plant is considered to have a substantial impact on the harbor zooplankton community.

Four holoplanktonic species: the copepods, *Acrocalanus inermis* and *Oithona simplex*, the arrow worm *Sagitta enflata*, the sergestid shrimp *Lucifer chacei* and five meroplanktonic taxa: *Balanus* nauplii, gastropod veligers, bivalve veligers, brachyuran zoea and caridean larvae were selected from 40 taxa identified in the filter-pump samples. The results of this analysis are presented in table 8. Notice that while the discharge samples at power plant 2 contain significantly fewer individuals for all selected taxa, only *Sagitta enflata* and caridean

Table 4. Zooplankton concentration (mean number of individuals per cubic metre filtered from triplicate zooplankton net tows) by major taxonomic groups. Values are for the total number of individuals in a given category taken in a haul series divided by the total volume in the series. Pearl Harbor Study, August–October 1978

	Power Plant 3		Power Plant 2		STC (Ford Island)
Taxa / Tow Series	A	E	B	C	D
Medusae	–	–	5.92	–	–
Ctenophores	–	3.80	–	–	–
Polychaete larvae	10.73	3.30	17.18	2.83	10.61
Copepods/Calanoid*	8934.23	8454.14	21075.21	3715.86	1687.56
Copepods/Cyclopoid*	17731.01	278.19	13782.14	82.21	84.91
Copepods/Harpacticoid*	–	–	64.40	–	–
Copepods/Nauplii*	4879.46	–	128.81	–	–
All Copepods*	31544.70	8632.33	35050.56	3798.07	1772.47
Barnacle nauplii	124.67	328.67	1308.67	1024.25	456.11
Lucifer chacei (zoea)	76.33	234.67	72.67	50.83	10.61
Caridean larvae	35.37	–	341.76	42.70	13.57
Brachyuran zoea	46.31	30.25	183.41	313.14	12.78
Stomatopod alima	–	–	17.20	–	–
Gastropod veliger	29.65	14.25	102.38	–	9.24
Sagitta enflata	656.33	422.33	1155.67	60.18	224.23
Appendicularian larvae	–	9.90	–	–	–
Larval fish	11.45	3.80	46.26	–	–
Total individuals per cubic metre per sample	32535.54	9683.30	38255.42	5292.00	2509.62

*Copepod data are taken from a single, completely analyzed sample for each tow series (A–E).

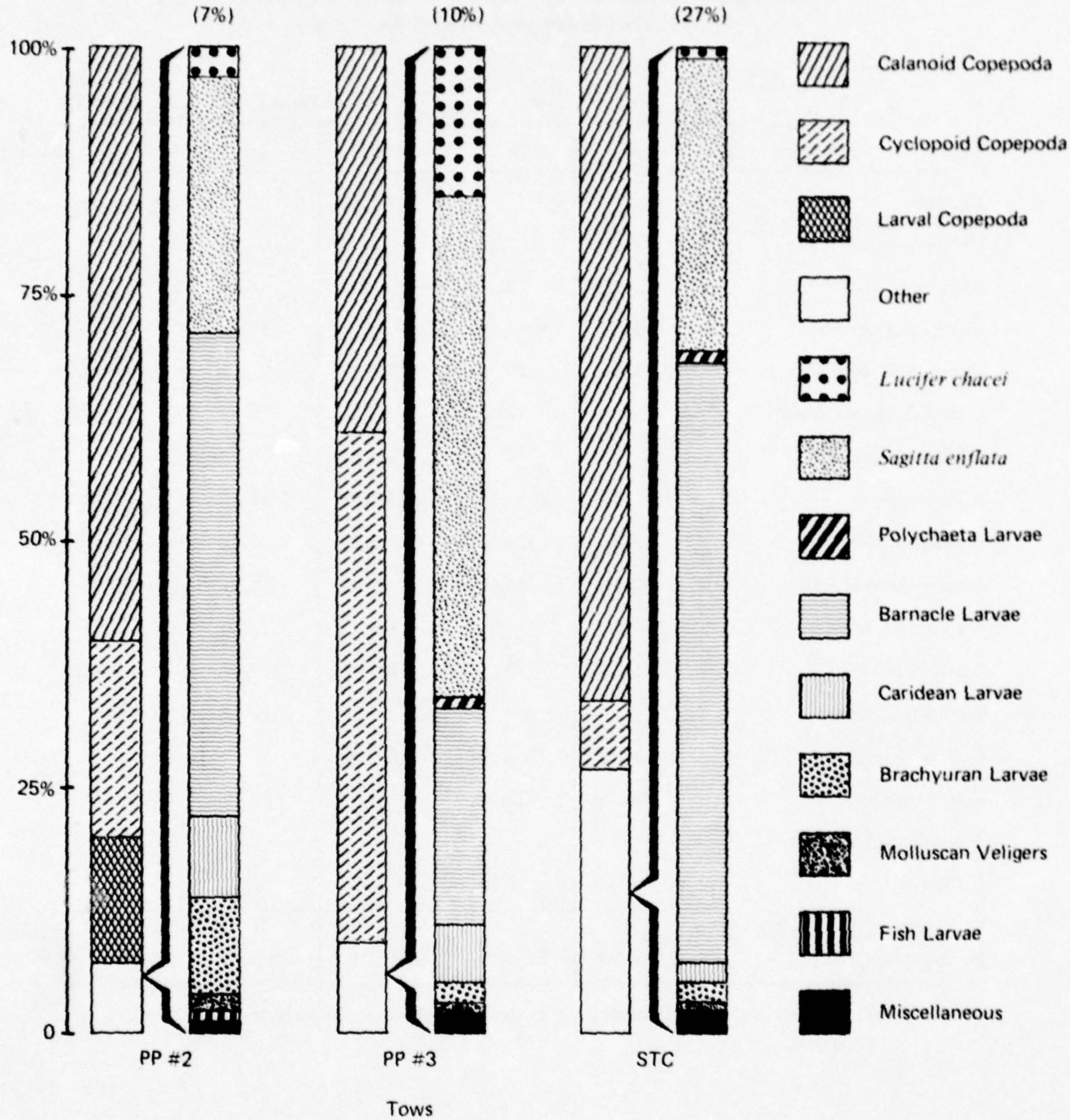


Figure 26. Percent composition of major zooplankton taxa present in tow net collections, Pearl Harbor Study, August–October 1978.

Table 5. Zooplankton filter-pump collections, data summary, Pearl Harbor Study, August–October 1978. All samples were collected during 30-minute periods; Site abbreviations are the same as used in table 2.

Sample #	Site	Time/Date	Mean Rate of Flow (l/min)	Volume Filtered (m^3)	Settled Volume (ml/m^3)	Tidal Conditions
1	PP3(I)	1221/30 Aug 78	24.67	.740	1.08	Incoming; Hi @ 1600 (+.6m)
2	PP3(D)	1343/30 Aug 78	28.07	.842	0.95	Incoming; Hi @ 1600 (+.6m)
3	PP2(I)	1524/30 Aug 78	23.75	.7125	0.28	Incoming; Hi @ 1600 (+.6m)
4	PP2(D)	1615/30 Aug 78	26.20	.786	0.10	Hi slack
5	PP3(I)	1007/14 Sep 78	30.10	.903	0.23	Incoming; Hi @ 1500 (+.6m)
6	PP3(D)	1116/14 Sep 78	42.30	1.269	0.39	Incoming; Hi @ 1500 (+.6m)
7	PP2(I)	1246/14 Sep 78	26.40	.792	0.54	Incoming; Hi @ 1500 (+.6m)
8	PP2(D)	1347/14 Sep 78	28.30	.849	0.18	Incoming; Hi @ 1500 (+.6m)
9	PP3(I)	0920/19 Sep 78	25.50	.756	0.23	Outgoing; Low @ 1200 (+.1m)
10	PP3(D)	1025/19 Sep 78	50.00	1.500	0.60	Outgoing; Low @ 1200 (+.1m)
11	PP2(I)	1130/19 Sep 78	28.30	.849	0.47	Outgoing; Low @ 1200 (+.1m)
12	PP2(D)	1221/19 Sep 78	28.70	.861	0.27	Low slack
13	PP3(I)	1004/26 Sep 78	29.50	.885	0.23	Incoming; Hi @ 1230 (+.5m)
14	PP3(D)	1055/26 Sep 78	51.10	1.533	0.33	Incoming; Hi @ 1230 (+.5m)
15	PP2(I)	1203/26 Sep 78	27.50	.825	0.28	Incoming; Hi @ 1230 (+.5m)
16	PP2(D)	1252/26 Sep 78	31.90	.957	0.21	Hi slack
17	PP3(I)	1034/28 Sep 78	31.90	.957	0.07	Incoming; Hi @ 1700 (+.5m)
18	PP3(D)	1140/28 Sep 78	44.90	1.347	0.41	Incoming; Hi @ 1700 (+.5m)
19	PP2(I)	1306/28 Sep 78	32.30	.969	0.29	Incoming; Hi @ 1700 (+.5m)
20	PP2(D)	1408/28 Sep 78	34.90	1.049	0.10	Incoming; Hi @ 1700 (+.5m)
21	PP3(I)	1109/3 Oct 78	35.80	1.074	0.47	Incoming; Low @ 1100 (+.1m)
22	PP3(D)	1219/3 Oct 78	43.80	1.314	0.15	Incoming; Low @ 1100 (+.1m)
23	PP2(I)	1327/3 Oct 78	35.60	1.068	0.47	Incoming; Low @ 1100 (+.1m)
24	PP2(D)	1415/3 Oct 78	38.10	1.143	0.70	Incoming; Low @ 1100 (+.1m)
25	PP3(I)	1403/10 Oct 78	30.00	.900	0.56	Outgoing; Low @ 1830 (+.1m)
26	PP3(D)	1458/10 Oct 78	49.50	1.485	0.43	Outgoing; Low @ 1830 (+.1m)
27	PP2(I)	1649/10 Oct 78	38.90	1.167	0.43	Outgoing; Low @ 1830 (+.1m)
28	PP2(D)	1807/10 Oct 78	38.20	1.146	0.79	Outgoing; Low @ 1830 (+.1m)
29	PP2(I)	1955/10 Oct 78	29.60	.888	0.45	Incoming
30	PP2(D)	1856/10 Oct 78	38.30	1.149	0.27	Low slack
31	PP2(I)	1512/17 Oct 78	38.40	1.152	0.78	Incoming; Hi @ 1645 (+.2m)
32	PP2(D)	1622/17 Oct 78	42.80	1.284	0.16	Slack
33	PP3(I)	1747/17 Oct 78	42.50	1.275	0.47	Outgoing

Table 6. Condensed plankton filter-pump data, Pearl Harbor Study, August–October 1978. Mean values for each site series. Standard deviations in parentheses. Site abbreviations are the same as for table 2.

Site	n	Mean Flow Rate (l/min)	Mean Volume Filtered (cubic metres)	Mean Settled Volume (ml/m^3)
PP3 (Intake)	8	31.21 (5.78)	0.94 (0.17)	0.42 (0.31)
PP3 (Disch.)	7	44.24 (7.89)	1.33 (0.24)	0.43 (0.27)
PP2 (Intake)	9	31.19 (5.42)	0.94 (0.16)	0.44 (0.16)
PP2 (Disch.)	9	34.16 (5.67)	1.02 (0.17)	0.31 (0.26)

Table 7. Checklist of planktonic biota collected using a filter-pump sampling system, Pearl Harbor Study, August–October 1978

Taxa	*Site	**Relative Abundance
Cnidaria		
Medusae	All	P
Annelida		
Polychaete larvae	All	C
Arthropoda/Crustacea		
Ostracoda		
Conchaecia sp.	2I/2D/3I	P
Copepoda		
Calanoida		
Acartia fossae cf. *hamata* (Mori, 1937)	2I/3I/3D	P
Acrocalanus gracilis Giesbrecht, 1888	2D/3I/3D	P
Acrocalanus inermis Sewell, 1912	All	V
Calocalanus pavo (Dana, 1849)	3D	R
Clausocalanus sp.	2I/3I/3D	P
Pontellina sp.	3D	R
Scolecithrix sp.	3I	R
Undulina vulgaris (Dana, 1849)	3I/3D	P
Cyclopoida		
Coryceus sp.	3D	R
Oithona linearis Giesbrecht, 1891	2I/3D	R
Oithona nana Giesbrecht, 1892	All	P
Oithona plumifera Baird, 1843	2I/3I/3D	P
Oithona simplex Farran, 1913	All	C
Oncaea venusta Phillipi, 1843	3I	R
Oncaea sp.	2I/3I/3D	P
Harpacticoida		
Aegisthus sp.	3I	R
Clytemnestra sp.	All	P
Euterpina acutifrons (Dana, 1847)	All	P
Microsetella sp.	3I/3D	R
Harpacticoids, unidentified	2D/3I/3D	P

Table 7. (Continued).

Taxa	*Site	**Relative Abundance
Arthropoda/Crustacea (Continued)		
Copepoda; nauplii larvae (combined)	21/31/3D	P
Cirripedia/*Balanus*		
Nauplii	All	V
Cypris larvae	21/31/3D	P
Malacostraca		
Isopoda	21/31	P
Amphipoda		
Gammaridea (several spp.)	All	C
Decapoda		
Lucifer chacei Bowman, 1966	All	C
Caridean larvae	All	C
Brachyura larvae	All	C
Malacostraca		
Stomatopoda		
Alima larvae	2D	R
Mollusca		
Gastropoda		
Gastropod veliger larvae	All	V
Bivalvia (=Pelecypoda)		
Bivalve veliger larvae	All	C
Chaetognatha		
Sagitta enflata Grassi, 1883	All	V
Sagitta regularis Aida, 1897	3I	R
Chordata		
Urochordata/Tunicata		
Appendicularian larvae	All	V
Vertebrata		
Osteichthyes		
Fish eggs	All	P
Fish larvae	2I/3I	P

Legend: *Sites – 2 = power plant 2, 3 = power plant 3, I = Intake; D = Discharge; **Relative Abundance: Rare = found in 1-2 samples; Present = 3-15 samples; Common = 16-25 samples; Very common = >25 samples.

larvae are significantly reduced in discharge samples from power plant 3. The number of moribund zooplankton (determined by the neutral red staining technique) in discharge collections at both power plant sites remained low but roughly equivalent.

Larval fish and fish eggs comprised a minor proportion of zooplankton samples. McCain (1974) discussed the abundant larval fish populations in Pearl Harbor, but the present data do not support this observation at the sites studied during the present survey.

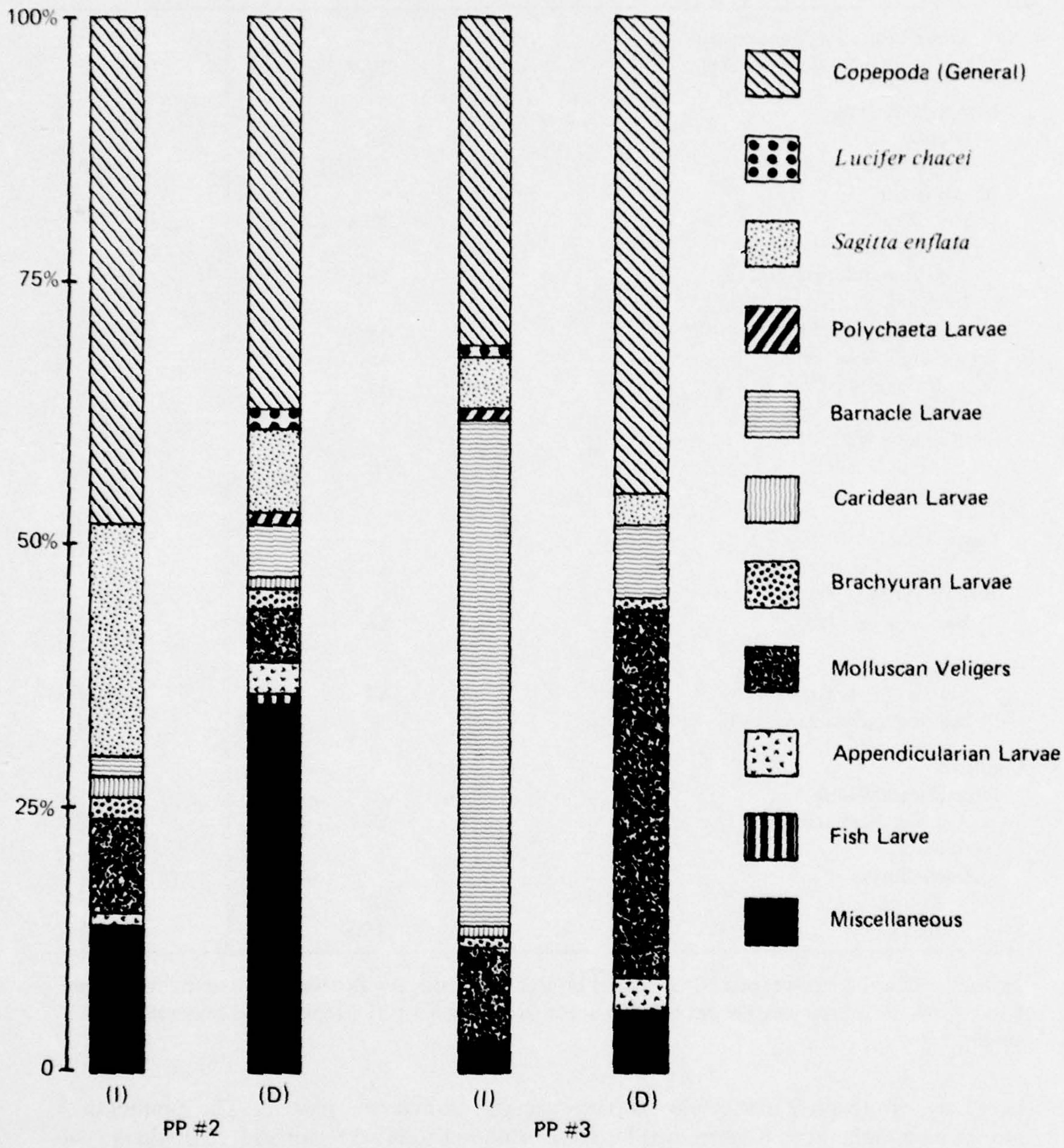


Figure 27. Percent composition of major zooplankton taxa present in filter-pump collections, Pearl Harbor Study, August-October 1978.

Table 8. Comparison of zooplankton data collected from intake and discharge areas at former power plants 2 and 3, Pearl Harbor Study, August–October 1978

Category	Power Plant 2 t-value	Power Plant 3 t-value
Acrocalanus inermis	3.19704**	-1.58099
Oithona simplex	2.40527*	1.50928
Sagitta enflata	3.06654**	2.46318*
Lucifer chacei	2.18218*	1.00597
Balanus spp.	4.09906**	1.25477
Gastropod veligers	3.11051**	-1.12237
Bivalve veligers	2.46154*	0.51756
Brachyura zoea	2.15980*	1.34474
Caridean larvae	3.69111**	2.76487*

*Significant at the 5% level
**Significant at the 1% level

Phytoplankton taken in tow net samples are presented in table 9. These preliminary results indicate that the diatom, *Skeletonema*, was numerically dominant among phytoplankton sampled in the harbor, and agree with the results from previous studies (Au, 1965: McCain, 1974).

Table 9. Percent composition of major algal taxa present in tow net samples, Pearl Harbor Study, August–October 1978. For site abbreviations, see legend, table 2.

Tow #/Site	*Skeletonema*	*Navicula*	*Chaetoceros*	*Nitzschia*	*Thalassionema*	*Melosira*	*Dictyocha*	*Pyrrophyta*
A-1/PP3(I/D)	95.9	0.1	1.4	0.8	1.8	–	–	–
A-2/PP3(I/D)	96.2	–	0.4	–	3.3	–	0.1	–
A-3/PP3(I/D)	98.2	–	1.0	–	0.8	–	–	–
B-1/PP2(D)	97.7	0.4	1.3	0.2	0.4	–	–	–
B-2/PP2(D)	96.3	–	–	0.7	3.0	–	–	–
B-3/PP2(D)	98.6	–	1.3	–	0.1	–	–	–
C-1/PP2(I)	98.8	0.1	0.7	0.3	–	–	–	0.1
C-2/PP2(I)	98.1	–	0.4	–	1.5	–	–	–
C-3/PP2(I)	95.6	0.1	3.0	–	0.3	1.0	–	–
D-1/STC(D)	97.2	–	2.4	–	0.4	–	–	–
D-2/STC(D)	98.9	–	0.2	–	0.8	–	0.1	–
D-3/STC(D)	96.3	–	3.5	0.1	0.1	–	–	–
E-1/PP3(I/D)	98.2	–	0.2	0.2	1.4	–	–	–
E-2/PP3(I/D)	94.4	0.1	4.6	–	0.9	–	–	–
E-3/PP3(I/D)	98.5	–	1.0	–	0.5	–	–	–

IMPINGEMENT/ENTRAPMENT

During this study, no commercially or recreationally important organisms were identified from the traveling screen site at power plant 2. The plant foreman, Mr. Luther Bartels, has mentioned that in previous years (during power generation) some fishes became entrapped at the traveling screen site; however, infrequently. Impingement of large numbers of nektonic forms did not occur during this investigation.

Organisms present in the impingement samples are summarized in table 10. Impingement collections performed at power plant 2 yielded primarily fouling data, and thus differ from results of other power plant studies performed in Hawaii (McCain, 1974; McCain, 1977) and elsewhere (Austin *et al.*, 1973; Fisher *et al.*, 1976; Lavaitis *et al.*, 1976) which considered only non-fouling organisms (i.e. fishes and motile invertebrates) to be significant. There were no economically valuable fishes or free-swimming macroinvertebrates collected in these samples. While anecdotal information from plant personnel indicates that impingement of potentially valuable biota has occurred in the past, the present collections suggest that there is negligible impact from impingement or entrapment at power plant 2. Observations at power plant 3 have verified that entrapment or impingement does not occur at this site because no screening devices exist there.

Table 10. Checklist of organisms present in impingement samples, Pearl Harbor Study, August–October 1978

Taxa	Occurrence
FORAMINIFERA	
Foraminifera, unid.	R
PORIFERA	
fragments, unidentified	C
COELENTERATA	
Hydrozoa	
Tubularia sp.	R
Halocordyle disticha (Goldfuss, 1820)	C
Obelia dichotoma (Linnaeus, 1758)	P
Anthozoa	
Anemones, unid.	U
PLATYHELMINTHES	
Turbellaria, unid.	P
NEMERTEA	
Nemertea, unid.	R
NEMATODA	
Nematoda, unid.	U
BRYOZOA	
Holoporella spp. (2)	R
Watersipora edmondsoni Soule & Soule, 1968	R
Bugula spp. (2)	R
Amathia distans Busk, 1886	R
ANNELIDA	
Polychaetes	
Chaetopteridae	C
MOLLUSCA	
Bivalves	
Hiatella hawaiiensis (Dall, Bartsch & Rehder, 1938)	P
ARTHROPODA – CRUSTACEA	
Copepoda	
Harpacticoida, unid.	R
Ostracoda	
Cylindroleberididae	R
Mysidacea	
Heteromysis sp.	P
Isopoda	
Mesanthura hieroglyphica Miller and Menzies, 1952	P
Amphipoda	
Ericthonius brasiliensis Dana, 1852	C
Podocerus brasiliensis Dana, 1853	V
Stenothoe gallensis cf. also *S. valida*	C
Natantia	
Palaemon pacificus (?)	R
ARTHROPODA – PYCNOGONIDA	
Anoplodactylus portus Calman, 1927	C
Endeis spp. (2)	C
Pigrogromitus timsanus Calman, 1927	R

Table 10. (Continued).

Taxa	Occurrence
ECHINODERMATA	
Ophiuroids, unid.	V
Holothuria, unid.	P
TUNICATA	
solitary, tunicates, unid.	P
	32 taxa

Legend: Rare = present in 1 sample or at <5% mean frequency; Present = 2-3 samples, 2-10 individuals, or 5-50% mean frequency; Common = 2-3 samples, 11-50 individuals, or 51-70% mean frequency; Very common = >3 samples, >50 individuals, or >70% mean frequency.

HABITAT FORMERS

Fouling data have been analyzed to describe and compare initial epifaunal settlement at three locations in Pearl Harbor. Triplicate fouling panels of each substratum (PVC and asbestos) were exposed at power plants 2 and 3 from 21 September–6 October 1978 and again from 6–19 October 1978. At the Submarine Training Center (Ford Island) site, panels were exposed from 21 September–12 October 1978 and again from 12–26 October 1978. The three-week exposure at Ford Island was the result of support boat malfunction, and planned retrieval was delayed for an extra week. Additionally, single panels of each type were exposed during the period 12–26 October at each site. These typical two-week settlement patterns are shown in panel photographs (figure 28).

Fifty-two fouling taxa were identified from biota attached to panels or present in panel washings (table 11). The number of fouling taxa present and their abundance were greater at power plant 3 than at power plant 2 and the Submarine Training Center (Ford Island). Yet, the numerical abundance and number of taxa were greater at the Ford Island site than at power plant 2.

Seven dominant fouling groups were identified from biota enumerated during grid count analyses. These selected groups are: "amphipod tubes" (tubes of detritus and adhesive, built on the substratum by various species of tubicolous amphipods, primarily *Ericthonius brasiliensis* at these sites), "*Balanus*" (*B. reticulatus* and juveniles), "Bryozoa" (combining *Holoporella* and *Watersipora*), "Campanularids" (combining primarily *Obelia dichotoma* and *Clytia hemisphaerica*, which can only be distinguished at higher magnification than used in grid counts), *Diplosoma macdonaldi*, "*Hydroides*" (primarily *H. elegans*) and "Spirorbinae" (several species of this serpulid polychaete subfamily). Statistics for frequency counts are presented in table 12.

The results of this analysis are presented in table 13, which indicates that for six fouling groups ("amphipod tubes," "*Balanus*," "Bryozoa," "Campanularids," "*Hydroides*" and "Spirorbinae") frequency of occurrence is significantly related to location. Substrate is significantly related to the occurrence of only two groups (Bryozoa and Spirorbinae), and for Bryozoa the significance is barely below the 5-percent level. Thus, substratum does not

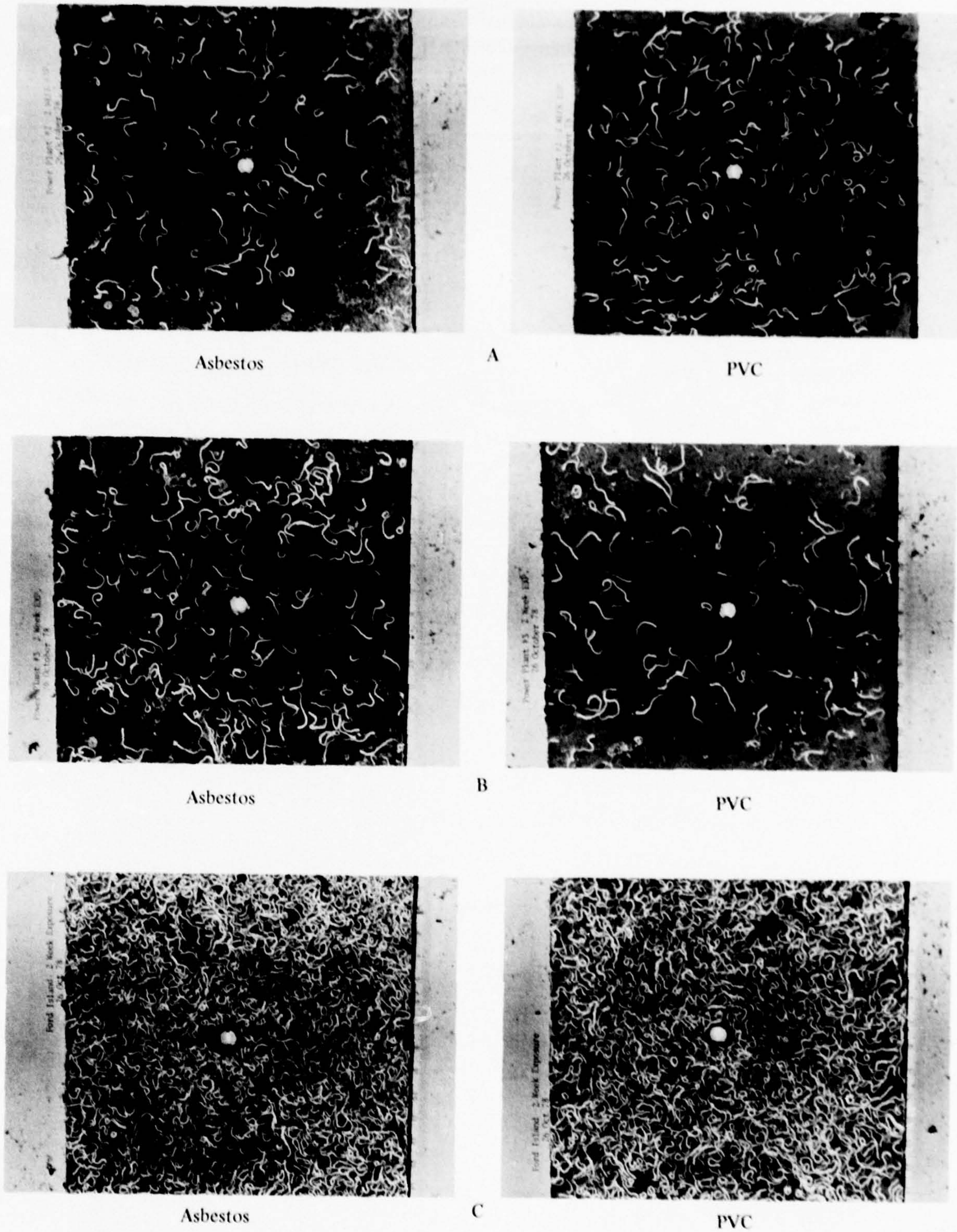


Figure 28. Laboratory photographs of typical two-week fouling growth on test panels: A – PP2, B – PP3 and C – SubTraCen (Ford Island).

Table 11. List of fouling biota collected from three study sites in Pearl Harbor, August–October 1978

Taxa	Power Plant 2	Power Plant 3	SubTraCen (Ford Island)
FORAMINIFERA			
Foraminifera, unid.	–	R	–
COELENTERATA			
Hydrozoa			
Bougainvilliidae	C	R	C
Clavidae	P	P	–
Clytia hemisphaerica (Linnaeus, 1767)	V	V	V
Obelia bidentata (?)	–	R	–
Obelia dichotoma (Linnaeus, 1758)	V	V	V
Sertulariidae	–	R	–
Anthozoa			
Anemones, unid.	–	–	P
PLATYHELMINTHES			
Turbellaria, unid.	P	C	C
NEMATODA			
Nematoda, unid.	P	C	–
BRYOZOA			
Holoporella spp. (2)	R	P	P
Watersipora edmondsoni Soule & Soule, 1968	–	P	P
Bugula spp. (2)	–	P	–
Amathia distans Busk, 1886	–	R	–
ANNELIDA			
Polychaetes			
Spirorbinae	R	C	P
Hydroides spp. (2) (primarily *H. elegans*)	V	V	V
MOLLUSCA			
Bivalves			
Hiatella hawaiensis (Dall, Bartsch & Rehder, 1938)	–	P	–
Anomia nobilis Reeve, 1859	P	P	P
Brachidontes crebristriatus Conrad, 1837	–	R	–
Gastropods			
Vermetidae	–	R	P
ARTHROPODA – CRUSTACEA			
Copepoda			
Harpacticoida, unid.	R	C	C
Cirripedia			
Balanus reticulatus Utinomi, 1967	R	P	P
Balanus spp. (juvenile)	P	P	P
Ostracoda			
Cylindroleberididae	R	–	P

Table 11. (Continued).

Taxa	Power Plant 2	Power Plant 3	SubTraCen (Ford Island)
ARTHROPODA – CRUSTACEA (Continued)			
Tanaidacea			
Leptochelia dubia (?) (Kroyer, 1852)	R	–	P
Anatanais insularis Miller, 1940	R	R	R
Isopoda			
Mesanthura hieroglyphica Miller and Menzies, 1952	R	–	–
Paracerceis sculpta (Holmes, 1909)	–	–	R
Dynamenella sp.	R	R	R
Amphipoda			
Paracaprella pusilla Mayer, 1890	–	R	–
Ericthonius brasiliensis (Dana, 1853)	V	V	V
Podocerus brasiliensis (Dana, 1853)	C	V	C
Stenothoe gallensis cf. also *S. valida*	P	C	P
Corophium baconi Shoemaker, 1934	R	P	C
Photis hawaiiensis J. L. Barnard, 1955	–	P	C
Elasmopus piikoi J. L. Barnard, 1970	R	P	P
Elasmopus rapax Costa, 1853	–	–	R
Leucothoe hyhelia J. L. Barnard, 1965	R	–	P
Natantia			
Palaemon pacificus (?)	–	R	–
ARTHROPODA – PYCNOGONIDA			
Anoplodactylus portus Calman, 1927	C	C	R
Endeis spp. (2)	C	C	R
Ammothella biunguiculata (Dohrn, 1881)	–	C	R
ECHINODERMATA			
Ophiuroids, unid.	R	–	–
TUNICATA			
Botrylloides sp.	C	P	P
Symplegma connectans Tokioka, 1949	R	P	P
Diplosoma macdonaldi Herdman, 1886	C	P	C
Dideminidae, unid.	C	P	P
solitary tunicates unid.	R	P	P
	35	44	38

Legend: Rare = present in 1 sample or at <5% mean frequency; Present = 2-3 samples, 2-10 individuals, or 5-50% mean frequency; Common = 2-3 samples, 11-50 individuals, or 51-70% mean frequency; Very common = >3 samples, >50 individuals, or >70% mean frequency.

Table 12. Percent frequencies of selected fouling biota at three sites, Pearl Harbor Study, August–October 1978

Taxa (n = 6)	Power Plant 2		Power Plant 3		*SubTraCen (Ford Island)	
	X̄	s	X̄	s	X̄	s
PVC Panels						
Amphipod Tubes	16.00	19.02	4.50	2.26	15.00	4.34
Balanus	.83	.55	2.33	2.58	1.00	1.10
Bryozoa	.50	.55	2.83	1.60	2.83	2.32
Campanularids	66.50	23.37	23.67	11.66	71.67	38.10
Diplosoma macdonaldi	4.67	1.86	7.33	3.20	12.67	9.25
Hydroides	14.66	3.38	37.50	7.18	72.17	28.87
Spirorbinae	1.17	1.17	3.50	1.64	1.17	1.51
Asbestos Panels						
Amphipod Tubes	15.17	16.57	1.83	1.34	11.83	7.73
Balanus	1.33	1.51	3.33	1.86	5.50	4.04
Bryozoa	1.17	.41	6.00	3.90	3.67	1.97
Campanularids	59.67	12.06	40.50	23.48	79.83	18.36
Diplosoma macdonaldi	8.33	5.85	2.17	2.14	10.50	7.01
Hydroides	22.33	4.76	25.33	3.27	74.50	27.89
Spirorbinae	1.17	1.17	9.17	3.43	1.17	.98

*Includes 3-week exposure data for first series (see text); all other data are for 2-week settlement record.

Table 13. Analysis of variance (ANOVA) for fouling data obtained at two sites in Pearl Harbor, August–October 1978

Taxa	Substrata		Location		Interaction	
	F†	p	F†	p	F†	p
Amphipod Tubes	.120	.732	6.032	.022*	.031	.861
Balanus	.995	.329	5.419	.029*	.106	.748
Bryozoa	4.604	.043*	16.092	<.001***	2.057	.166
Campanularids	.407	.530	15.657	<.001***	2.438	.134
Diplosoma macdonaldi	.257	.617	1.398	.250	8.906	.007**
Hydroides	1.260	.274	41.580	<.001***	24.509	<.001***
Spirorbinae	11.202	.003**	37.248	<.001***	11.202	.003**

†F-values and p's are after pooling the interaction and errors sums of squares if interactions is non-significant.
*significance at the 5% level
**significance at the 1% level
***significance greater than .1%

appear to influence settlement of fouling organisms as strongly as other conditions (such as water temperature, pollutant load, water chemistry, etc) at these two locations.

While the fouling community in Pearl Harbor is generally diagnostic for the estuary (compared with other locations in Hawaii) each location exhibited certain singularities in fouling characteristics during two week exposures. The percent frequencies at power plant 3 were lower than at power plant 2 for "amphipod tubes" and "Campanularids," while higher for "*Balanus*," "Bryozoa," "*Hydroides*," and "Spirorbinae," species that are more typically distributed by ships. Considering interactions between substrata and locations, the percent frequency was higher for *Diplosoma macdonaldi* on PVC at power plant 3, but higher on asbestos at power plant 2. Similarly, while the percent frequency of *Hydroides* was higher at power plant 3, the difference was more pronounced on PVC than on the asbestos panels. While "Spirorbinae" were also more numerous at power plant 3, the difference in this taxa was more pronounced on the asbestos panels.

NEKTON

Field observations and fish trap collections were similar to those previously reported from Pearl Harbor (Evans, 1974). Estuarine nektonic biota comprise an important recreational and potentially commercial resource in the harbor. Fortunately, from a Navy operational standpoint, the most valuable fishes and macroinvertebrates are presently located away from the shipyard and Southeast Loch regions of Pearl Harbor. Nehu, for instance, are primarily concentrated in West, Middle and Northeast Loch areas (Uchida and Sumida, 1971). Certain motile species such as juvenile *Caranx* (several species), *Elops hawaiiensis* and *Mugil cephalus*, move freely about the harbor and were collected most often from West Loch, Middle Loch, East Loch and either end of Ford Island (Evans, 1974). Most nektonic species are capable of avoiding or leaving unsuitable environments.

Ichthyological data gathered during the present study are combined with relevant data from prior investigations (Evans *et al.*, 1972; Evans, 1974) and presented in table 14. Five representative species have been selected from this listing and are described in detail (see appendix A). Previously reported patterns of fish distribution in Pearl Harbor (Evans, 1974; McCain, 1974; Peeling, Grovhoug and Evans, 1972) have been examined and observations during the current study have generally verified those data. No indication of adverse environmental effects attributable to cooling water systems on nektonic assemblages were observed during this phase of the study at three sites. A new distributional record for one species of butterflyfish, *Chaetodon ephippium* Cuvier and Valenciennes, 1831, was obtained from trap collections (several individuals) adjacent to power plant 3.

Table 14. Checklist of fishes observed at three sites, Pearl Harbor Study, August–October 1978

Family (Common Name; Hawaiian Name) Genus & Species (Naming authority and date)	PP2	PP3	STC
Acanthuridae (Surgeonfishes, Tangs; Palani, Pualu)			
Acanthurus dussumeri C & V, 1835	–	C	C
A. mata C & V, 1835	–	C	P
A. xanthopterus C & V, 1835	V	V	C
Naso brevirostris (C & V, 1835)	–	P	–
Zebrasoma flavescens (Bennett, 1828)	–	P	–
Apogonidae (Cardinalfishes; Upapalu)			
Apogon snyderi J & E, 1903	–	P	P
Foa brachygrammus (Jenkins, 1903)	–	P	P
Belonidae (Needlefish, Stickfish; Aha-aha)			
Tylosurus crocodilus (Peron & LeSueur, 1821)	–	R	–
Blenniidae (Blenny; Pao'o)			
Omobranchus elongatus (Peters, 1855)	–	P	P
Carangidae (Jacks; Papio)			
Caranx mate C & V, 1833	P	C	–
C. melampygus C & V, 1833	P	C	–
C. sexfasciatus Q & G, 1825	–	P	P
Gnathanodon speciosus Forskal, 1775	P	P	–
Carcharhinidae (Small Blacktip Shark, Volador; Mano)			
Carcharhinus limbatus Muller & Henle, 1841	–	R	–
Chaetodontidae (Butterflyfishes; Lau hau, Kika kapu)			
Chaetodon auriga Forskal, 1775	P	V	C
C. ephippium C & V, 1831	–	P	–
C. lunula (Lacepede, 1802)	–	C	–
C. miliaris Q & G, 1825	–	V	–
Chanidae (Milkfish; Awa)			
Chanos chanos (Forskal, 1775)	–	P	–
Congridae (White Eel; Puhi uha)			
Conger cinreus (Ruppell, 1828)	–	C	–
Diodontidae (Porcupinefish; O'opu-kawa)			
Diodon holocanthus Linne, 1758	–	P	–
D. hystrix Linne, 1758	–	P	–
Eleotridae (Sleeper Goby; O'o'pu)			
Asterropteryx semipunctatus Ruppell, 1821	T	T	T
Elopidae (Hawaiian Tarpon, Tenpounder; Awa-awa)			
Elops hawaiensis Regan, 1909	–	P	–
Engraulidae (Hawaiian Anchovy; Nehu)			
Stolephorus purpureus Fowler, 1900	P	C	P

Table 14. (Continued)

Family (Common Name; Hawaiian Name) Genus & Species (Naming authority and date)	PP2	PP3	STC
Gobiidae (Gobies; O'o'pu)			
Ctenogobius tongarevae (Fowler, 1927)	–	P	P
Gnatholepis anjerensis (Bleeker, 1850)	–	P	–
Opua nephodes Jordan, 1925	–	R	–
Hemiramphidae (Halfbeak; Iheihe, Me'e-me'e)			
Hemiramphus depauperatus Lay & Bennett, 1839	–	C	P
Holocentridae (Squirrelfishes; Ala'ihi, Menpachi)			
Flammeo sammara (Forskal, 1775)	–	P	–
Myripristis murdjan (Forskal, 1775)	–	R	–
Kuhliidae (Mountain bass, Flagtails; Aholehole)			
Kuhlia sandvicensis (Steindachner, 1876)	P	C	P
Labridae (Wrasse; Hinalea)			
Stethojulis balteata (Q & G, 1824)	–	R	P
Mugilidae (Striped mullet; Ama-ama)			
Mugil cephalus Linne, 1758	P	P	P
Mullidae (Goatfishes; Weke; Kumu)			
Mulloidichthys samoensis (Gunther, 1878)	R	P	–
Parupeneus pleurostigma (Bennett, 1831)	–	R	–
P. porphyreus (Jenkins, 1903)	C	C	P
Upeneus arge J & E, 1903	–	P	–
Muraenidae (Moray; Puhi Laumilo)			
Gymnothorax undulatus (Lacepede, 1803)	P	C	P
Myliobatidae (Eagle Ray; Hihimanu)			
Aetobatus narinari (Euphrasen, 1790)	–	P	–
Ostraciontidae (Boxfish; O'opakahu)			
Ostracion meleagris camurum (Jenkins, 1901)	–	P	–
Polynemidae (Threadfin; Moi)			
Polydactylus sexfilis (C & V, 1831)	–	C	–
Pomacentridae (Damselfish; Mamo, Aloiloi)			
Abudefduf abdominalis Q & G, 1824	–	C	P
Dascyllus albisella Gill, 1862	–	P	–
Scaridae (Parrotfishes; Uhu)			
Calotomus spinidens Q & G, 1824	–	R	–
Sphyraenidae (Barracuda; Kaku)			
Sphyraena barracuda (Walbaum, 1792)	–	P	P
Synodontidae (Lizardfishes; Ulae)			
Saurida gracilis (Q & G, 1824)	–	P	P

Table 14. (Continued).

Family (Common Name; Hawaiian Name) Genus & Species (Naming authority and date)	PP2	PP3	STC
Sphyrnidae (Scalloped Hammerhead; Mano kihikihi)			
Sphyrna lewini (Griffith & Smith, 1834)	P	C	P
Tetraodontidae (Soft Puffers; Maki maki)			
Arothron hispidus (Linne, 1758)	V	V	C
Zanclidae (Moorish Idol; Kihikihi)			
Zanclus cornutus (Linne, 1758)	–	P	P
	14	50	24

Legend: T = too numerous to count; V = very common (10+); C = common (6-10); P = present (2-5); R = rare (1); C & V = Cuvier and Valenciennes, J & E = Jordan and Evermann, Q & G = Quoy and Gaimard.

BENTHOS

Benthic biota identified from collections obtained during this study are listed in table 15. Forty-three taxa and their relative abundances at various study sites are presented in this list. Comparisons with previously collected benthic data (Evans, 1974) suggest that no measurable changes have occurred in the benthic communities of Pearl Harbor. This component of the harbor ecosystem is apparently quite stable.

Table 15 indicates that the discharge site at the Submarine Training Center (Ford Island) has the most diverse benthic assemblage of the three sites, with 37 recorded taxa. Samples from study sites adjacent to discharges from power plants 2 and 3 contained 21 and 24 taxa, respectively. Previous intensive collections at the power plant 3 site (Evans, 1974) recorded 32 taxa at this site. When compared with nine other stations in the harbor, this assemblage is about midway in numerical abundance of different taxa. The rapidly sloping bottom combined with a rather monotonous soft mud and debris substrata tends to decrease the number of taxa at this site, and at power plant 2.

Two members of the benthic community, the stone crab, *Thalamita integra*, and the nestling clam, *Hiatella hawaiensis*, have been selected for further discussion in appendix A. Adult benthic fauna are essentially unaffected by cooling water systems in the harbor. However, larval forms from the benthos are susceptible to entrainment effects. Examination of data collected during this investigation does not demonstrate adverse effects for either larval or adult benthic organisms adjacent to study sites.

Table 15. List of benthic biota collected from three study sites in Pearl Harbor, August–October 1978

Taxa	Power Plant 2	Power Plant 3	SubTraCen (Ford Island)
PORIFERA			
Terpios zeteki de Laubenfels, 1936	–	–	R
fragments, unidentified	R	–	R
NEMERTEA			
Nemertea, unid.	R	–	P
NEMATODA			
Nematoda, unid.	R	C	P
ANNELIDA			
Oligochaetes			
Tubificidae	V	C	V
Polychaetes			
Polynoidae	–	–	R
Amphinomidae	–	–	P
Phyllodocidae	–	–	R
Hesionidae	R	R	P
Syllidae	R	R	C
Nereidae	R	–	R
Eunicidae	R	R	P
Dorvilleidae	R	–	R
Spionidae	R	R	C
Cirratulidae	V	C	V
Capitellidae	R	P	C
Chaetopteridae	–	C	–
Orbiniidae	R	R	P
Paraonidae	–	–	P
Opheliidae	R	P	R
Cossuridae	–	–	R
Sabellariidae	–	R	–
Terebellidae	–	R	R
Sabellidae	–	R	P
Serpulidae			
Hydroides spp. (2)	–	R	R
MOLLUSCA			
Bivalves			
Ostrea sp.	–	–	P
Hiatella hawaiensis (Dall, Bartsch & Rehder, 1938)	R	–	P
Brachidontes cerebrestriatus (Conrad, 1837)	–	R	–
Gastropods			
Crepidula aculeata Gmelin, 1791	–	–	P
ARTHROPODA/CRUSTACEA			
Ostracoda			
Cylindroleberididae	R	–	R

Table 15. (Continued).

Taxa	Power Plant 2	Power Plant 3	SubTraCen (Ford Island)
ARTHROPODA/CRUSTACEA (Continued)			
Tanaidacea			
Apseudes sp. 1	–	–	P
Apseudes sp. 2	P	–	V
Cirolana sp. cf. *C. parva*	P	R	P
Amphipoda			
Ericthonius brasiliensis Dana, 1852	–	P	–
Lembos macromanus (Shoemaker, 1925)	R	R	P
Corophium insidiosum Crawford, 1937	–	–	R
Natantia			
Alpheus mackayi Banner & Banner, 1974	–	–	P
Alpheus rapacida de Man, 1911	P	R	–
Palaemonidae, unid.	–	R	R
Brachyura			
Thalamita integra Dana, 1852	–	R	–
SIPUNCULA			
Sipunculid, unid.	–	–	P
ECHINODERMATA			
Ophiuroids, unid.	P	–	–
TUNICATA			
Didemnidae, unid.	–	R	R
	21	24	37

Legend: Rare = present in 1 sample or at <5% mean frequency; Present = 2-3 samples, 2-10 individuals, or 5-50% mean frequency; Common = 2-3 samples, 11-50 individuals, or 51-70% mean frequency; Very common = >3 samples, >50 individuals, or >70% mean frequency.

WATER COLUMN

Temperature data collected during this study are shown in figure 29. Each site exhibited a different and specific thermal response. At all three sites, effluent water is discharged onto surface harbor waters. Field observations indicate that thermal effects remain primarily at the surface. As seen in figure 29a, heated effluent water from power plant 3 is readily detectable at the surface; however, on several occasions, cooler water was recorded from one-metre depths at the discharge when compared with simultaneous intake temperatures. At this station, the discharge is located along a near-vertical ledge where maximum harbor depths (about 20 metres) have been recorded only 50 metres from the discharge shoreline. Power plant 2 exhibits the highest discharge temperatures observed in the harbor, yet these elevated thermal conditions are also generally restricted to the upper metre of the water column. Figure 29b shows the thermal effects of boiler shut-down on two occasions and the corresponding resumption of plant operations. Even with significantly elevated discharge temperatures, biota adjacent to the discharge from power plant 2 is diverse and abundant. The Submarine Training Center on Ford Island does not appear to contribute any

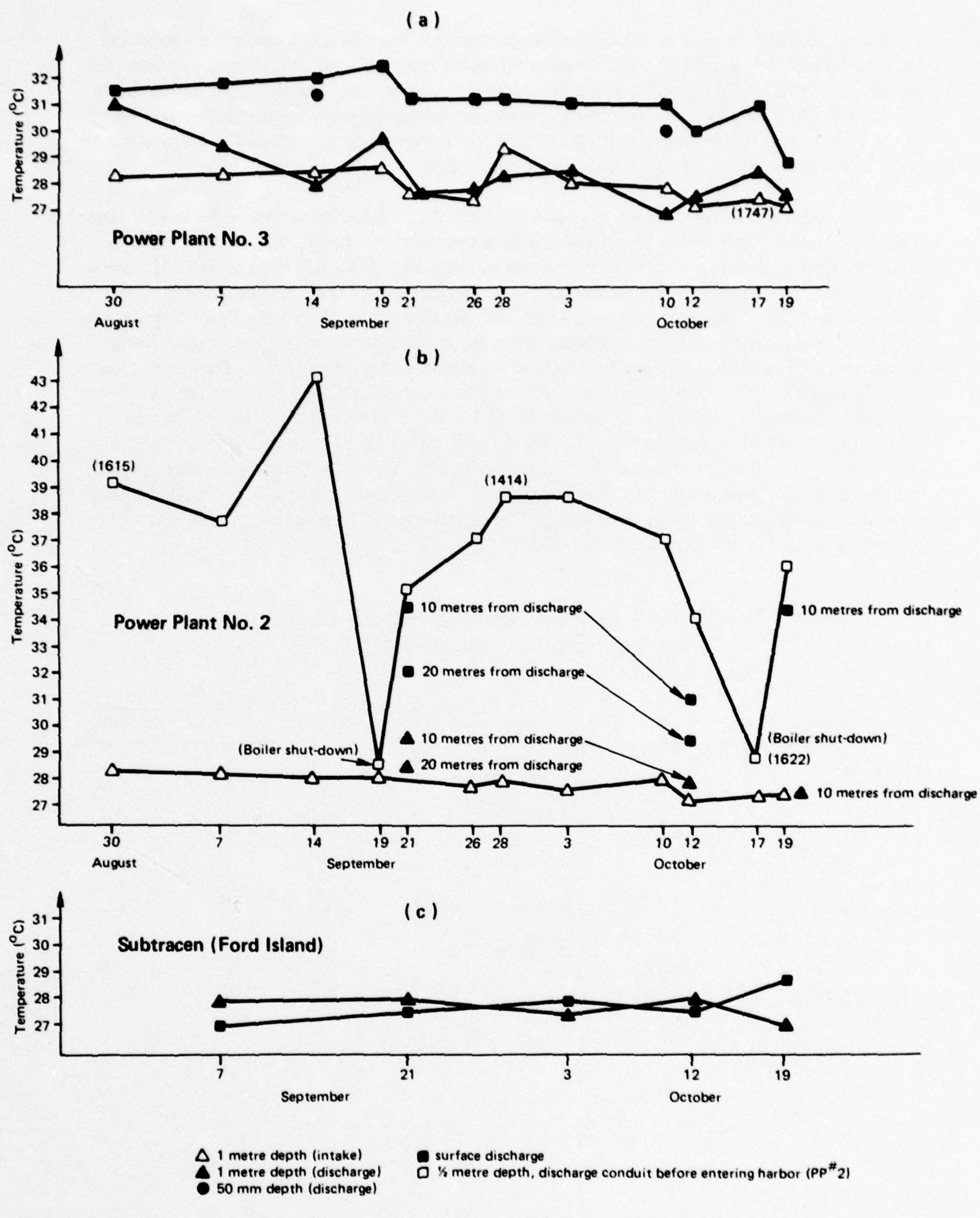


Figure 29. Temperature data collected at three sites, Pearl Harbor Study, August-October 1978.

significant thermal anomalies to the harbor (see figure 29c). On three out of five sampling dates, discharge temperatures were measurably lower than ambient. Cooling water from the Submarine Training Center is fresh water, yet no adverse effects of dilution on harbor biota adjacent to the discharge were observed. Maximum-minimum temperature data recorded at study sites during this survey are listed in table 16. Power plant 2 exhibits the greatest range and highest temperatures in data from three study sites.

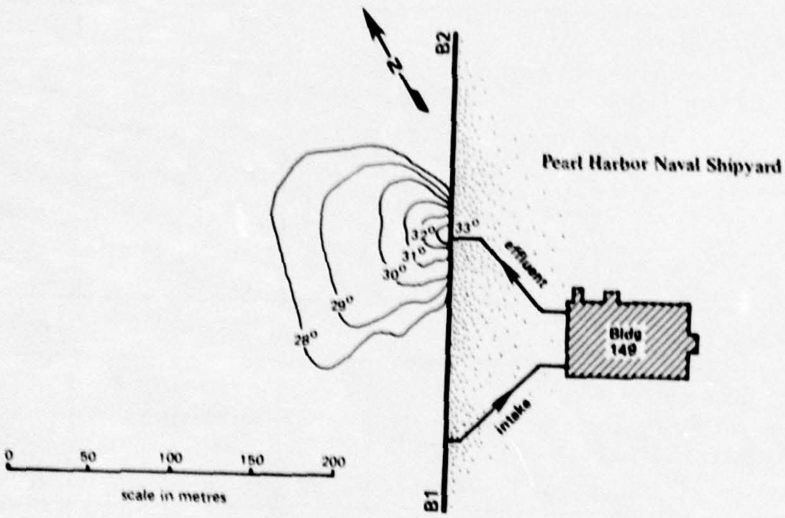
Water-motion data collected at power plants 2 and 3 are presented in table 17. These data indicate that both sites experience similar water motion conditions. The integrated water motion values from clod-card exposures indicate that the study sites in Pearl Harbor are relatively low water motion environments, compared to other Pacific Basin sites (Grovhoug, 1978; Henderson and Grovhoug, unpublished data). From the dye studies made during normal plant operations, residence times for cooling water in the plants were determined to be 25 minutes at power plant 2 and 45 minutes at power plant 3. Discharge plume characteristics for each site during trade wind conditions are depicted in figure 30. At power plant 2, the plume was visually detectable for about 100 metres out into South Channel (toward Ford Island, see figure 1). Mild northeasterly trade winds tended to push the plume in a westerly direction during slack low tidal conditions. The area of thermal influence was restricted to the upper metre of the water column. Power plant 3 exhibited a localized thermal effect in surface waters. The discharge plume returned to near ambient conditions within 25 metres of the discharge structure.

Table 16. Maximum-minimum water temperature data recorded at three sites, Pearl Harbor Study, August–October 1978

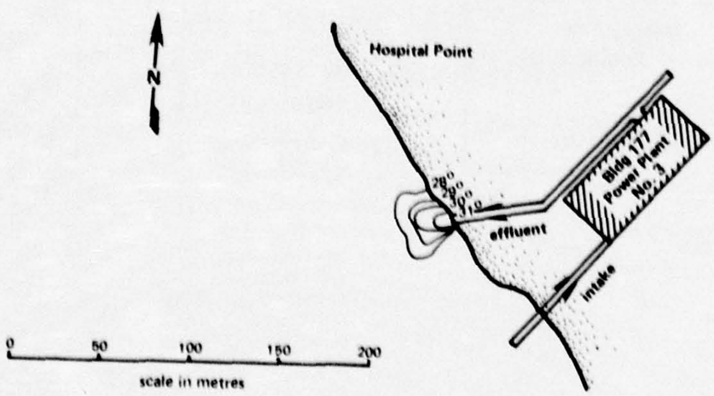
Location	Date(s)	Temperature (°C)	
		Maximum	Minimum
Power plant 2	6-12 Oct 78	37.0	31.0
	12-17 Oct 78	40.0	29.0
	17-19 Oct 78	39.5	26.0
Power plant 3	12-19 Oct 78	31.8	24.9
	19-26 Oct 78	30.5	26.0
SubTraCen (Ford Island)	19-26 Oct 78	29.5	25.5

Table 17. Clod-card data from power plants 2 and 3, Pearl Harbor Study, August–October 1978

Date(s)		Site					
		Power plant 2			Power plant 3		
21–26 September 1978	Duration (Hours)	118.25			121.50		
	Replicate number	1	2	3	1	2	3
	Weight Loss (gm)	30.86	29.88	29.00	27.17	24.80	26.46
	(gm/hour)	0.26	0.25	0.25	0.22	0.20	0.22
	Water Motion (cm/sec)	5.57	5.43	5.43	4.65	4.15	4.65
	$\bar{X}$		5.48,			4.48,	
	s		0.08			0.29	
12–17 October 1978	Duration (Hours)	125.92			125.50		
	Replicate number	1	2	3	1	2	3
	Weight Loss (gm)	28.76	27.55	21.47	26.86	30.41	32.21
	(gm/hour)	0.23	0.22	0.17	0.21	0.24	0.26
	Water Motion (cm/sec)	5.00	4.72	3.30	4.43	5.28	5.85
	$\bar{X}$		4.34,			5.19,	
	s		0.91			0.71	
	Overall Site Means, Water Motion for two periods (cm/sec)						
	$\bar{X}$		4.91,			4.84,	
	s		0.81			0.50	



A. Former Power Plant No. 2



B. Former Power Plant No. 3

Figure 30. Discharge plume characteristics at two sites, measured during dye studies on 19 October 1978, Pearl Harbor Study, August–October 1978.

REPRESENTATIVE IMPORTANT BIOTA

Nineteen taxa were selected as representative important biota from the three study areas in Pearl Harbor. These organisms are listed in table 18 and represent a wide range of environmental requirements and attributes such as behavioral responses, feeding types, habitat desiderata, and phyletic diversity. The list includes five species of fishes, three meroplanktonic groups, three species of holoplankton, one chlorophyte alga, a serpulid polychaete worm, a tube-dwelling amphipod, one common acorn barnacle, a ubiquitous crab, one nestling clam, a colonial bryozoan and a common species of compound tunicate. Each of these selected taxa functions in the maintenance of the Pearl Harbor ecosystem. Existing harbor biotic assemblages represent a complex mixture of indigenous and exotic forms (the latter often introduced from ships) that have varied responses to alterations (man-induced or natural) in the environment.

These selected biota are individually discussed in appendix A. Taxonomic information, distributional patterns, trophic relationships within the harbor ecosystem, cooling water systems effects on each taxon and the estimated ecological and economic significance of each form are presented in narrative descriptions. Line drawings of typical members of each taxon are also provided.

Table 18. Representative important biota selected from data collected during a Pearl Harbor Study, August–October 1978

Taxon	Common Name	Feeding Type	Remarks
Ulva spp. (several)	Sea Lettuce; limu; green alga	Autotrophic	Habitat former; Chlorophyte
Hydroides elegans	Tubeworm; serpulid polychaete worm	Filter feeder	Sessile fouler; gregarious
Balanus reticulatus	Acorn barnacle; sessile cirriped	Filter feeder	Sessile fouler; gregarious
Ericthonius brasiliensis	Gammarid amphipod; crustacean	Filter feeder	Motile epifaunal fouler; tube dweller
Thalamita integra	Stone crab; decapod crustacean	Scavenger	Benthic; solitary ubiquitous
Hiatella hawaiensis	Nestling clam: bivalve mollusc	Filter feeder	Epifaunal; Benthic; habitat former
Bugula neritina	Erect bryozoan; sessile ectoproct	Carnivore	Sessile fouler; colonial
Diplosoma macdonaldi	Compound tunicate; Urochordate	Filter feeder	Sessile fouler; colonial
Acrocalanus inermis	Copepod; planktonic microcrustacean	Herbivore	Holoplanktonic
Lucifer chacei	Sergestid shrimp; ghost shrimp	Omnivore	Holoplanktonic
Sagitta enflata	Arrow worm; Chaetognath	Carnivore	Holoplanktonic
Balanus nauplii	Barnacle larvae	Filter feeder	Meroplanktonic
Molluscan veliger	Mollusc larvae	Filter feeder	Meroplanktonic
Brachyuran zoea	Crab larvae	Filter feeder	Meroplanktonic
Acanthurus xanthopterus	Surgeonfish; Pualu	Herbivore; Grazer	Schooling species
Arothron hispidus	Soft puffer; Maki maki	Omnivore	Solitary species
Caranx melampygus	Jack; omilu ulua; papio	Mid-water carnivore	Schooling species
Parupeneus porphyreus	Goatfish; kumu	Benthic carnivore	Gregarious species
Stolephorus purpureus	Hawaiian anchovy; nehu (baitfish)	Planktivore	Schooling species

DISCUSSION AND CONCLUSIONS

GENERAL

The primary objective of this investigation was to evaluate the impact of cooling water systems on marine communities adjacent to three sites in Pearl Harbor, two of which operate both intake and discharge structures and use harbor water as a cooling medium, while the third site discharges heated freshwater into the estuary. Generally, cooling water systems at the study sites produce only minor and localized impacts on the harbor ecosystem. Pearl Harbor contains a multifaceted estuarine ecosystem which has been significantly modified by human activities. Harbor biota have demonstrated a remarkable resiliency to various perturbations during the past 50 years. Present ecological conditions in Pearl Harbor represent a complex mixture of indigenous and exotic biota with varied responses to man-induced alterations, pollutant stresses and changes in harbor dynamics. Site-specific patterns in the data and environmental comparisons between the sites are discussed in this section.

INTAKE AREAS

Studies at intake areas of power plants 2 and 3 provided data for entrainment, entrapment and (for power plant 2) impingement evaluations. These studies include tow-net and filter-pump plankton samples, diving and photographic observations, settlement patterns on fouling panels and nekton data from fish trap samples and previous studies.

DISCHARGE AREAS

The effects of thermal effluent discharge at all three sites were examined using temperature data, dye studies, underwater observations, fish trap samples, benthos data and plankton collections. Zone of mixing estimates were made for each discharge site.

POWER PLANT 2

This site could have several impacts on the Pearl Harbor ecosystem particularly through entrainment of zooplankton and larval fishes and elevated water temperatures in effluent discharges. Although mortality of entrained zooplankton is apparently greater at this site than at power plant 3, overall impingement of economically significant biota was negligible during the study. The cooling water effluent temperature is quite elevated at this site. However, even the worst-case analysis of this site suggests only minor effects on the adjacent harbor ecosystem from heated effluent. Adverse effects are localized within several hundred metres of the discharge. Data suggest that the present zone of mixing could be reduced to a 500-metre radius from the point of discharge (figure 30). Even during Kona (south) wind or strong northeast trade wind conditions, the proposed zone of mixing would be adequate. An increase in wind speed appears to accelerate the mixing of surface waters with the cooler underlying water mass. Evaporative cooling is also enhanced during increased wind conditions. The impact of the thermal discharge at this site is further reduced by frequent ship traffic (causing significant mixing) along channel areas (Evans, 1974). No antifouling chemicals, such as chlorine, are used in the cooling water system at this site.

POWER PLANT 3

This site has been consistently evaluated to have less impact on the harbor ecosystem than power plant 2. The proximity to deeper, open channel water areas (figure 1), as well as only a minor elevation in discharge water temperature, support a negligible adverse impact evaluation. Plankton, nekton and epifaunal communities adjacent to this site appear to be thriving. The zone of mixing (figure 30) extends less than a 30-metre radius into the harbor during most wind and tidal conditions. Entrainment effects represent the only demonstrated adverse impact on the harbor ecosystem and even these effects are localized and of negligible impact to the planktonic ecosystem. Again, power plant 3 does not employ any intake screening devices, and no antifouling chemicals such as chlorine are added to the system at this site.

SUBMARINE TRAINING CENTER

The Ford Island discharge site under pier F-1 exhibits typical East Loch biotic assemblages. Impact from the thermal discharge is negligible. Planktonic, nektonic, epifaunal and benthic communities show no indication of adverse effects from the discharge. The zone of mixing is estimated to extend a maximum of 10 metres from the discharge structure (remaining entirely under the pier). No antifouling chemicals are used and cooling water effluent at this site exhibits no measurable impact on adjacent harbor biotic assemblages.

BIOLOGICAL OBSERVATIONS

The inherent variability of plankton densities, primarily due to patchiness in estuarine systems, is a well-known phenomenon (Copeland *et al.*, 1976; Edmondson, 1937; Raymont, 1963; Riley, 1967). The present collections provide a general validation of patterns observed in previously collected harbor plankton data (McCain, 1974; Grovhoug, unpublished data). McCain (1974) discusses several relevant features of the Pearl Harbor planktonic ecosystem in comparison to Kaneohe Bay: 1) phytoplankton biomass is approximately three times higher in Pearl Harbor; 2) herbivorous and carnivorous zooplankton biomass in the two Hawaiian embayments is remarkably similar; and 3) the larval fish populations in Pearl Harbor are notably higher than in Kaneohe Bay. Data collected during the present study yielded few larval fish specimens; however, seasonal or diurnal variability may partially explain this observation. More larval fish were present in late afternoon to sunset collection periods.

In general aspect, the Pearl Harbor zooplankton communities are similar to those observed in Kaneohe Bay (Smith, 1978). Open coastal holoplanktonic forms are more common in Pearl Harbor samples than in Kaneohe Bay samples (Vijaya Gopalakrishnan, personal communication). Meroplanktonic forms (those life stages, often larvae or eggs, of fishes and macroinvertebrates which reside as plankton during part of their life cycle) are important components of the Pearl Harbor plankton ecosystem and were well-represented in plankton collections.

The total number of zooplankton present in filter-pump samples from power plant 2 intake areas is consistently lower when compared with power plant 3 intake collections. This pattern suggests that power plant 2 occupies a location within the harbor (i.e. adjacent to the Pearl Harbor Naval Shipyard and major ship berthing facilities in Southeast Loch) which may already be reduced in environmental suitability for various planktonic taxa.

This pattern was also suggested by fouling panel settlement data. While power plant 2 appears to exert a greater entrainment impact, the actual effects are probably minimized because of its location, restricted area of influence and the reduced volume of cooling water presently used when compared with past plant data.

Impingement was evaluated at power plant 2, the only study site where intake screening devices exist. Impingement of large concentrations of jellyfish has also occurred during fall and early winter months. Intensive field observations during previous harbor studies (Evans, 1974) have also documented the seasonal abundance of the rhizostome jellyfish, *Phyllorhiza punctata* von Lendenfeld, 1884 [as *Mastigias papua* (Lesson)]. The densest concentrations of this organism have been observed in West Loch; however, individuals have been reported from nearly all areas in the harbor. Impingement of other nonfouling (motile) macroinvertebrates or fishes was insignificant during this study.

Marine fouling organisms represent the primary habitat formers in the Pearl Harbor ecosystem. One objective for examining short-term fouling response was to obtain quantitative data linking larval availability with existing longer-term settlement patterns on pilings and other underwater structures at the study sites. Additionally, the epifaunal fouling community has recently been shown to reflect an integrated response to harbor environmental conditions (Rastetter and Cooke, in press). Data from fouling panel arrays exposed for two-week intervals were collected at study sites during this investigation.

The number of fouling taxa present and their abundance was greater at power plant 3 than at power plant 2 and the Submarine Training Center (Ford Island). Yet, the numerical abundance and number of taxa were greater at the Ford Island site than at power plant 2. Considering the Submarine Training Center discharge site as the most typical or "normal" in relation to fouling, for the East Loch region of Pearl Harbor, the effect of power plant 2 is to decrease fouling community parameters, both in number of taxa and number of individuals, in those data. This pattern was seen in plankton data as well. The fouling community at power plant 3 is more diverse than the other study sites, probably because of its location in a less stressed area of the harbor.

The butterflyfish, *Chaetodon ephippium*, collected adjacent to power plant 3 is more typical of clearwater, open coastal reef and sandy bottom environments. A food habit study in the Marshall Islands by Hiatt and Strasburg (1960) describes this species as one which feeds on living coral polyps and algae, primarily, but also has been reported to ingest crustacea and polychaete worms. The presence of this species may suggest that certain areas of Pearl Harbor may be returning to more "reeflike" conditions. Other members of the nektonic ecosystem represent more typical Hawaiian estuarine forms. No significant impact on nektonic biota was attributable to cooling water systems during this study.

Benthic fauna present at discharge sites generally represent typical forms for the Pearl Harbor ecosystem. There was no indication of adverse effects attributable to the naval installations under evaluation during this study. The distribution of harbor bottom communities appears to be influenced most strongly by available substrata and depth in Pearl Harbor.

SUMMARY OBSERVATIONS

A summary of impact at cooling water structures for representative taxa/categories measured during this investigation is provided in table 19. The values given represent quantitative estimates of impact experienced in the immediate vicinity (within 10 metres) of cooling water structures. The discharge structure at power plant 2 exhibited the greatest impact on harbor biota. Power plant 3 had much less impact on the harbor ecosystem. The Submarine Training Center discharge slightly enhanced assemblages of some biota, yet the overall impact at this structure is negligible.

Planktonic and epifaunal biota were generally the most susceptible forms to adverse impact. While some assemblages in these groups were significantly reduced in number, certain forms such as *Ulva* (a green alga), *Acanthurus xanthopterus* (a herbivorous surgeonfish), *Arothron hispidus* (a soft puffer) and *Hiatella hawaiensis* (a nestling clam) were enhanced

Table 19. Summary of impact at intake and discharge structures, Pearl Harbor Study, August – October 1978. Impact values represent estimated percent reduction (-) or enhancement (+) in the immediate vicinity of the structure.

Component	Representative Taxon/Category	Impact PP 2 I	Impact PP 2 D	Impact PP 3 I	Impact PP 3 D	Impact STC D
Plankton	*Acrocalanus inermis*	-15	-80	-20	+15	0
	Lucifer chacei	-25	-50	-10	-30	0
	Sagitta enflata	-20	-50	-10	-25	0
	Balanus nauplii	-30	-60	-25	-40	+5
	Molluscan veligers	-20	-40	-5	-15	0
	Brachyuran zoea	-10	-30	-5	-10	+5
Epifauna	*Ulva* spp.	0	+5	+10	+30	0
	Hydroides elegans	0	-20	+10	-10	+10
	Ericthonius brasiliensis	-20	-30	+10	-10	+10
	Balanus reticulatus	-5	-15	+20	-10	+20
	Bugula neritina	0	-10	0	-5	+15
	Diplosoma macdonaldi	+10	0	0	-10	+10
Nekton	*Acanthurus xanthopterus*	+10	0	+10	+15	+5
	Arothron hispidus	0	+10	+5	+20	+10
	Caranx melampygus	0	0	0	+30	0
	Parupeneus porphyreus	0	0	0	0	0
	Stolephorus purpureus	0	-10	0	-5	0
Benthos	*Hiatella hawaiensis*	+10	-10	+10	0	+5
	Thalamita integra	0	0	0	+5	+10
Water Column	Temperature	0	+50	0	+15	0
	Movement (Motion)	+10	+10	+5	+5	+5

near cooling water structures. Other biota such as the goatfish, *Parupeneus porphyreus* and the crab, *Thalamita integra* were relatively unaffected at study sites.

In general, the cooling water systems studied during this investigation represent only minor and quite localized impacts on the overall Pearl Harbor ecosystem. The three study sites have provided useful environmental data which serve to further expand present knowledge of this complex Hawaiian estuary.

APPENDIX A

Representative Important Biota

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This appendix presents descriptive information and line drawings of selected representative organisms encountered during this study. These biota have been listed previously in table 18 and are further described in this appendix.

Ulva is a geographically widespread genus of benthic marine algae (Tsuda, 1968), that may serve as an indicator of high nutrient environments (Borowitzka, 1972; Littler and Murray, 1975). Several species of *Ulva* have been reported from Pearl Harbor (Evans, 1974) including: *Ulva fasciata* Delile "limu palahalaha," *U. lactuca* Linne "limu ilioha or limu pakaea" and *U. reticulata* Forskal. *U. fasciata* (figure A-1) is considered edible (Abbott and Williamson, 1974) and is harvested around Oahu for both home consumption and public sale in local markets. *Ulva* is often found in estuarine areas along shallow flats, usually attached to hard objects such as rocks, shells or metallic debris. *Ulva* is also a diet item for certain other vertebrates such as shore birds and fishes. Several surgeonfishes (including *Acanthurus xanthopterus, A. mata* and *A. dussumeri*), striped mullet (*Mugil cephalus*) and milkfish (*Chanos chanos*) are known to feed on *Ulva* in Pearl Harbor (Evans, 1974). This species is a habitat former that bonds and modifies the substratum and provides surface area on which other organisms may settle. The presence of *Ulva* at study sites is restricted to a narrow intertidal zone (about 150mm wide) on vertical pilings and along the rock ledge and concrete discharge structure at power plant 3. *Ulva* distribution is influenced by the combined effects of nutrient availability, fish grazing, intolerance to desiccation and sunlight exposure. *Ulva* was not observed in shaded environments (such as under piers or inside conduits). It occurred in an apparently healthy state adjacent to the discharge plume at power plant 2 attached to outer pilings exposed to water 4–7°C warmer than ambient, and thus may have a considerable degree of thermal tolerance. No distinctive distributional patterns for *Ulva* were observed in Pearl Harbor during this investigation. Present cooling water systems operations do not appear to adversely affect this chlorophyte alga in Pearl Harbor.

Hydroides elegans (Haswell, 1883) (figure A-2) is a sessile serpulid polychaete worm that is a major fouling organism with world-wide distribution. The species previously reported as *Hydroides norvegica* Gunnerus, 1768 (Grovhoug, 1976), has recently been

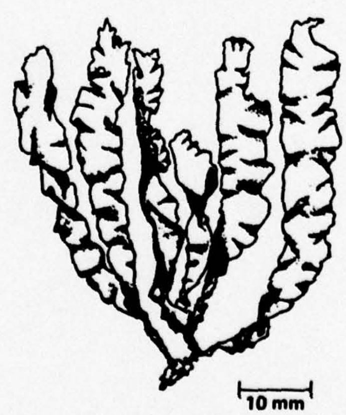

Figure A-1. *Ulva fasciata* (from Abbott, 1947).

Figure A-2. *Hydroides elegans* (drawn by Pat Brash).

identified as *Hydroides elegans* by Dr. Julie H. Brock, University of Hawaii, according to ten Hove (1974). *H. elegans* is a common member of estuarine Hawaiian fouling funa and was a dominant organism observed on fouling panels in Pearl Harbor during this investigation. From the standpoint of maritime operations, *H. elegans* is truly a nuisance species which creates severe fouling problems on ship hulls and in piping systems. The worm secretes a fragile, white calcareous tube which may have two longitudinal ridges along its upper surface. Initially, these tubes are formed along contours of the substratum, often beginning in a loose spiral. In some harbor areas such as Southeast Loch, further tube development proceeds in a straight growth form with the distal end of the tube often rising perpendicular to the substratum. *H. elegans* has been observed to form dense mats on fouling panels reaching a height of up to 110mm in three months (Grovhoug, 1976). Settlement and rapid growth of this species occur throughout the year in Pearl Harbor. Dense tube worm aggregations provide habitat for many other fouling organisms, such as bryozoans, mollusks and other polychaetes. *H. elegans* also contributes many larvae to the harbor plankton community. The effects of cooling water systems on this species are probably negligible in Pearl Harbor, due to the restricted site influences and widespread occurrence of this fouling organism within the harbor.

Balanus reticulatus Utinomi, 1967 is a circumtropical acorn barnacle that has been widely distributed by ships in most oceans of the world (Utinomi, 1967). This species is part of the *Balanus amphitrite* complex and is now considered synonymous with *Balanus amphitrite communis* Darwin, 1854 (Newman and Ross, 1976). In Hawaii, this species (figure A-3) is a dominant fouling form in embayments such as Pearl Harbor and Kaneohe Bay, Oahu (Grovhoug, 1976). *B. reticulatus* is a moderately stenohaline, subtidal species which is usually found in embayments that do not experience severe freshwater dilution. According to Utinomi (1967), this species is confined to the upper subtidal region (2–10 metres below MLLW). Recorded predators on adult barnacles from the harbor are: the

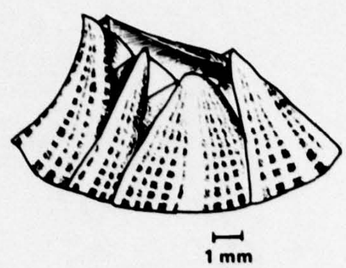

Figure A-3. *Balanus reticulatus* (drawn by Pat Brash).

surgeonfish (*Acanthurus mata*), which probably have ingested barnacles incidental to algal foraging; the tenpounder (*Elops hawaiiensis*); and the soft puffer (*Arothron hispidus*) (Evans, 1974). Adult barnacles attached to vertical pilings and other similar substrata in Pearl Harbor contribute vast numbers of larvae to the plankton. Zooplankton data collected during this study indicate the availability of barnacle larvae in harbor environments adjacent to study sites. Nauplii larvae provide a major source of food for filter feeding organisms in the harbor. Cooling water systems cause mortality to barnacle nauplii, yet the localized influence of these losses is considered insignificant to general ecosystem functions in the harbor.

Ericthonius brasiliensis (Dana, 1853), a gammarid amphipod which is widely distributed in tropical and temperate seas (Barnard, 1971) is shown in figure A-4. This filter-feeding species forms dense masses of silty tubes attached to pilings and docks in Pearl Harbor. *E. brasiliensis* is a prey species for many fishes in Pearl Harbor. Benthic carnivores such as bonefish (*Albula vulpes*) and various species of goatfishes (including *Parupeneus porphyreus* and *Mulloidichthys samoensis*), feed on gammarid amphipods in Pearl Harbor, according to Evans (1974). During this previous study *E. brasiliensis* was also very abundant on pilings. *E. brasiliensis* is described as a pollution-tolerant species that forms a significant component in estuarine ecosystems with high nutrients, concentrated organic detritus and turbid water conditions, such as the polluted environments of Los Angeles-Long Beach harbors in southern California (Barnard and Reish, 1959; Barnard, 1968). Ginn *et al.* (1974) reported high survival rates for gammarid amphipods during an entrainment effects study at Consolidated Edison's Indian Point nuclear power plant on the Hudson River estuary. Observations during the present study suggest that entrainment mortality for amphipods in Pearl Harbor is not critical to any function of the harbor ecosystem. The primary

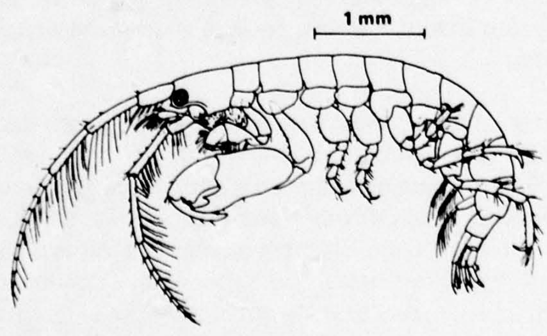

Figure A-4. *Ericthonius brasiliensis* (from Barnard, 1971).

contribution from *E. brasiliensis* to the Pearl Harbor ecosystem is probably as a source of food. This species is not appreciably affected by cooling water intake or discharge structures at study sites.

Thalamita integra Dana, 1852, a portunid crab which inhabits most benthic environments in Pearl Harbor (Evans, 1974), is shown in figure A-5. This species is a benthic scavenger that feeds on moribund or detrital material found on harbor bottom areas. *T. integra* is frequently collected from Pearl Harbor, for both market sale and home consumption. Piscine predators of *T. integra* have been identified as *Caranx sexfasciatus, Elops hawaiiensis, Parupeneus porphyreus* and *Sphyrna lewini* (Evans, 1974). Because of its benthic habitat, this species experiences little effect from cooling water systems in the harbor. Individual crabs have been observed immediately adjacent to cooling water tunnels for both power plants under study.

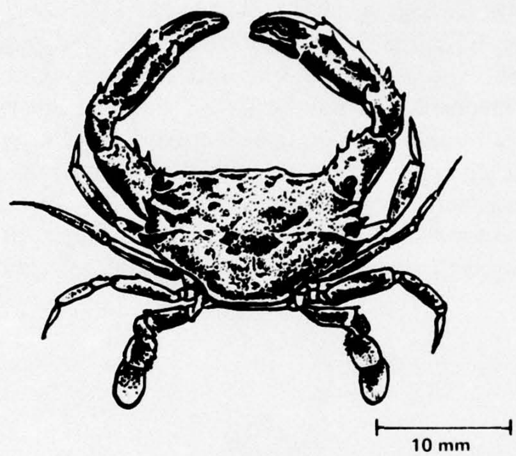

Figure A-5. *Thalamita integra* (from Edmondson, 1933).

Hiatella hawaiensis (Dall, Bartsch and Rehder, 1938) is a nestling clam which has a widespread distribution throughout Hawaiian estuarine environments. This species (figure A-6) commonly occurs nestled among epifaunal fouling organisms. As a juvenile, *H. hawaiensis* forms byssal threads which function to attach it to the substratum; adults have

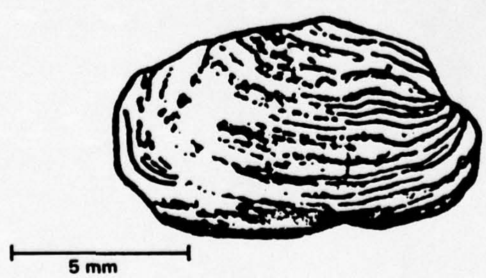

Figure A-6. *Hiatella hawaiensis* (from Dall, Bartsch and Rehder, 1938).

rock-boring capabilities as well (Yonge, 1971). This species was the most abundant benthic and pile-dwelling organism collected during extensive investigations at 10 stations in Pearl Harbor during the period 1971-1973 (Evans, 1974). *H. hawaiensis* is a filter-feeding bivalve which, while quite small in size (2-15mm), provides both food and habitat for other organisms in Pearl Harbor. Its veliger larvae (figure A-13) are susceptible to entrainment and ensuing mortality. Cooling water systems probably have a minor effect on the distribution of this species in the harbor.

Bugula neritina (Linnaeus, 1758) is a reddish-brown branching, erect bryozoan (figure A-7). This colonial organism is a common nearshore fouling species which is widely distributed around the world in warm temperate and tropical waters. On Oahu, this species has been reported from Pearl Harbor, Kaneohe Bay, Hawaii Kai, Ala Wai Yacht Basin, and Honolulu Harbor (Soule and Soule, 1968). *B. neritina* has been collected throughout the year from these Hawaiian waters and apparently reaches a maximum age of about ninety days (Edmondson, 1944; Grovhoug, 1976). Within Pearl Harbor, *B. neritina* is distributed in all lochs, particularly in Southeast Loch and in the naval shipyard and Hospital Point areas (Evans, 1974). This species is a planktivorous microcarnivore that utilizes a specialized "cage captor" feeding mechanism (Winston, 1978). Surrounding material is often stained reddish brown to purple by the leached pigment from dead *B. neritina* as moribund colonies fade to a dull brown or tan color. *B. neritina* colonies form a microhabitat for various other organisms, especially sea spiders (pycnogonids) and skeleton shrimp (caprellid amphipods). Cooling water systems do not adversely affect the distribution of *B. neritina* in Pearl Harbor, and conversely, data suggest that distribution and growth are favored for *Bugula* adjacent to study sites.

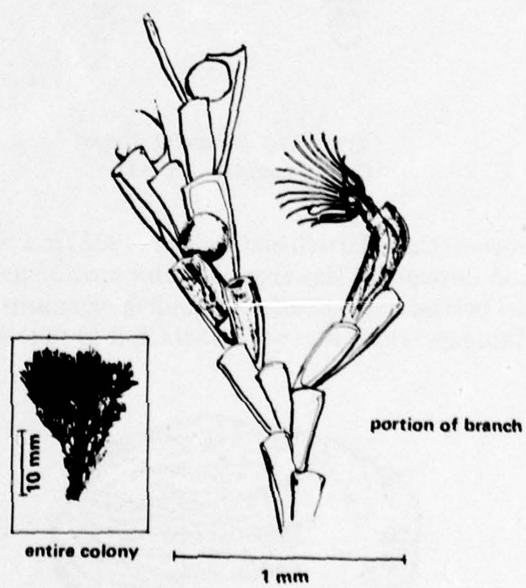

Figure A-7. *Bugula neritina* (drawn by Pat Brash and Walter Uchida).

Diplosoma macdonaldi Herdman, 1886 is a widely distributed compound tunicate and a principal early fouling organism on test panels in Pearl Harbor. This species has an extensive (nearly cosmopolitan) tropical and subtropical distribution. An entire colony and a single colony member (zooid) are shown in figure A-8. The individual zooids feed by filtering water through the branchial basket and removing small particles such as phytoplankton and microzooplankton. Tunicates provide a supplemental food source for some harbor fishes such as the soft puffer, *Arothron hispidus* (Evans, 1974; Hobson, 1974). Tunicates have been identified from the digestive tracts of the surgeonfish *Acanthurus xanthopterus*, but these were probably ingested incidentally while the fish were browsing on algae (Evans, 1974). *D. macdonaldi* apparently thrives in the nutrient-rich harbor environments adjacent to study sites in Pearl Harbor. Growth of this species is probably enhanced by elevated water temperatures and increased circulation patterns in areas adjacent to discharge sites.

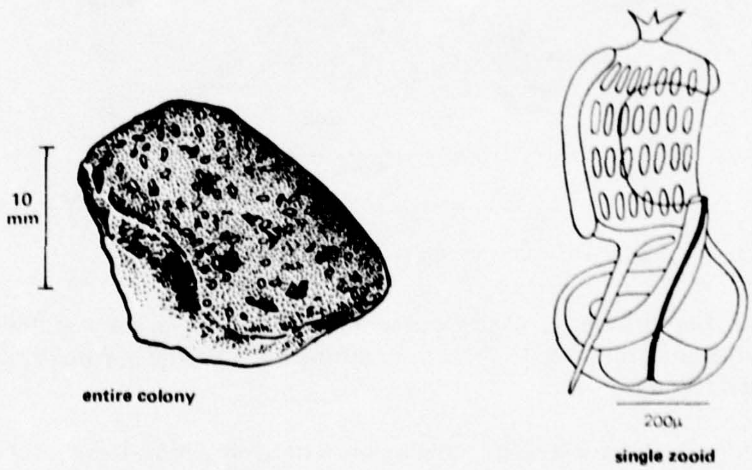

Figure A-8. *Diplosoma macdonaldi* (from Plough, 1978 and Eldredge, 1966).

Three representative holoplanktonic species have been selected as characteristic members of the Pearl Harbor planktonic ecosystem: the calanoid copepod, *Acrocalanus inermis* Sewell, 1912; the sergestid shrimp, *Lucifer chacei* Bowman, 1966; and the arrowworm, *Sagitta enflata* Grassi 1883. These organisms were present in both tow net and filter-pump collections from the study sites.

Acrocalanus inermis is a microcopepod (figure A-9) which was numerically dominant in zooplankton collections during this study. In Kaneohe Bay, Hirota (1977) identifies *A. inermis* as a major prey species for the carnivorous chaetognath, *Sagitta enflata*. This copepod is an important component of the Pearl Harbor ecosystem and apparently flourishes in all study areas. Entrainment mortality occurs in cooling water systems, but *A. inermis* populations are not appreciably reduced, even in areas immediately adjacent to study sites.

Both larval and adult forms of the ghost prawn (*Lucifer chacei*) were present in zooplankton collections (figure A-10). It has been identified as a common diet item for "nehu" (*Stolephorus purpureus*) in some estuarine areas on Oahu (Hiatt, 1947). While this organism is not an obligate carnivore (McCain, 1974), in Pearl Harbor its diet probably

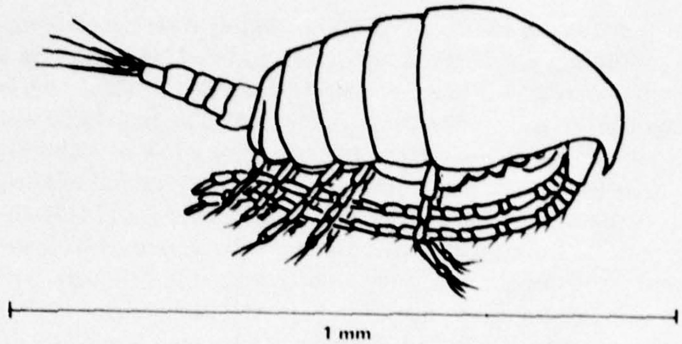

Figure A-9. *Acrocalanus inermis* (drawn by Pam Ching).

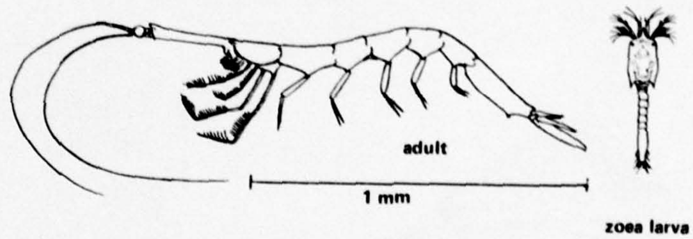

Figure A-10. *Lucifer chacei* (from Wickstead, 1965).

consists mainly of zooplankton. *L. chacei* was well-represented in all zooplankton net tows and was common in most filter-pump collections during this study; it apparently thrives in most areas of Pearl Harbor.

Sagitta enflata, a voracious carnivore, is shown in figure A-11. In a recent study (Hirota, 1977), the principal food for *S. enflata* in Kaneohe Bay was reported as micro-copepods, especially *Acrocalanus inermis, Oithona simplex* and *Euterpina acutifrons*, that are also common copepods in Pearl Harbor. Other prey species were copepod nauplii, the appendicularian (*Oikopleura*), *Stolephorus* larvae and other *Sagitta.* This species was present in all zooplankton collections made during this survey. The cooling water systems do not appear to significantly reduce the abundance of this species in Pearl Harbor. Many individuals were observed in power plant 3 discharge samples in an apparently healthy condition, indicating through-plant survival.

Three meroplanktonic groups have also been selected as representative of major larval components in the Pearl Harbor ecosystem: barnacle (*Balanus*) nauplii, molluscan veliger larvae and brachyuran (crab) zoea.

Barnacle nauplii (figure A-12) were abundant in nearly all zooplankton collections. These active, motile forms provide a substantial source of food for many filter-feeding and carnivorous organisms in the harbor ecosystem. Barnes (1962) and Crisp (1974) have discussed larval release and settlement behavior for several species of *Balanus.* Barnacle larvae are nearly continuously available in Hawaiian estuaries (Grovhoug, 1976). Entrainment mortality occurs to these fragile forms, but the abundance of nauplii, even in discharge

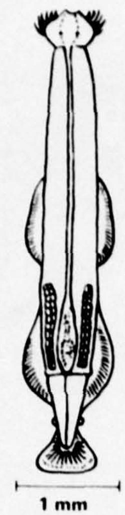

Figure A-11. *Sagitta enflata* (from Wickstead, 1965).

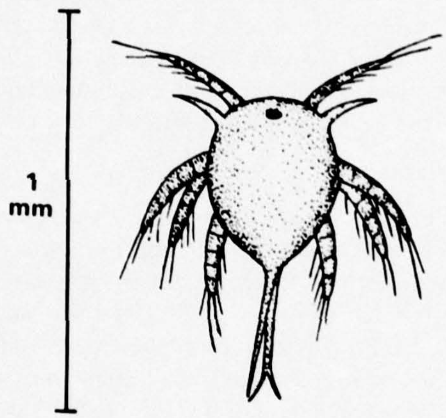

Figure A-12. Barnacle nauplius larva (from Barnes, 1963).

collections, suggests that adverse effects from cooling water systems are very localized in the harbor.

Molluscan veliger larvae (figure A-13) were also numerically abundant in most zooplankton samples. These common larvae presumably originate from species with abundant adult populations in the harbor, such as *Hiatella hawaiensis*, oysters, vermetids, etc. Larval molluscs are probably quite susceptible to pumped entrainment mortality (Beck and Miller, 1974; Copeland *et al.*, 1976), but this study's data suggest that the effects of entrainment are very localized because adult oysters and vermetid molluscs are very common in areas adjacent to the study sites. Adams (1969) demonstrated that the elevated temperature regimes at several California power generating plants were favorable to the setting and growth of many molluscan species.

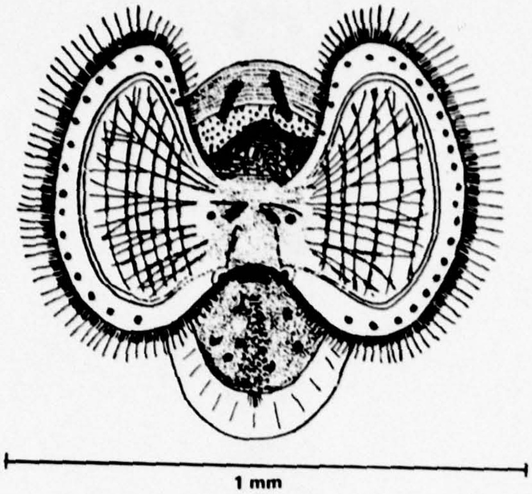

Figure A-13. Molluscan veliger larva (from Barnes, 1963).

Brachyuran (i.e. crab) zoea larvae (figure A-14) are another meroplanktonic group which provide abundant food for many harbor organisms. These active, motile forms were well-represented in most zooplankton collections during the study. Zoea larvae were especially numerous in tow net collections off power plant 2 (table 4 and figure 26). This group of larval zooplankton does experience entrainment mortality, but the influence of cooling water appears to be very localized.

The yellow-finned surgeonfish, *Acanthurus xanthopterus* Cuvier and Valenciennes, 1835 (figure A-15) is known in Hawaii as the "pualu" and has a wide tropical distribution throughout the Indo-Pacific from western Mexico to eastern Africa (Tinker, 1978). This species is described as a grazing herbivore (Evans, 1974; Hiatt and Strasburg, 1960; Jones, 1968), although one specimen from Pearl Harbor had ingested several tunicates, probably incidental to algal grazing. *A. xanthopterus* is the largest member of this genus in Hawaii, and sometimes reaches a length of nearly one-half metre. "Pualu" are schooling fish and are

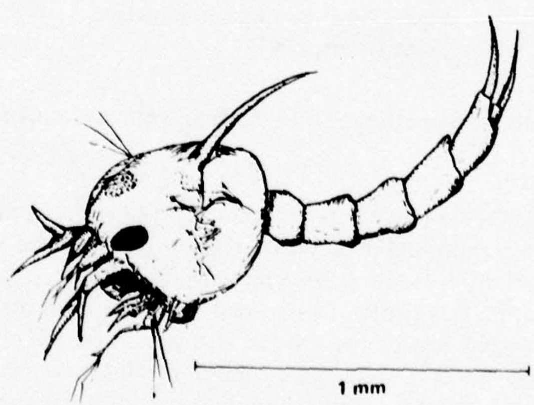

Figure A-14. Brachyuran zoea larva (drawn by J. Grovhoug).

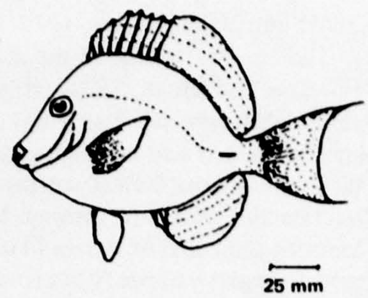

Figure A-15. *Acanthurus xanthopterus* (drawn by J. Grovhoug).

one of the commonest species around pier and piling habitats in Pearl Harbor. *A. xanthopterus* is readily captured in fish traps (McCain, 1974) and by hook and line fishing (Gosline and Brock, 1960). During trapping and fish tagging investigations in the northern sector of East Loch, Pearl Harbor, McCain (1974) demonstrated that *A. xanthopterus* move about the harbor more than other species encountered. This species is considered recreationally and commercially important. *A. xanthopterus* has been implicated in outbreaks of ciguatera (tropical fish poisoning) in Hawaiian waters (Halstead, 1967; Helfrich, 1963). Data collected previously from Pearl Harbor (Evans, 1974) and observations made during this study do not indicate any adverse distributional effects attributable to cooling water systems for this species.

Arothron hispidus (Linnaeus, 1758), the soft puffer or "maki maki," (figure A-16) is widely distributed throughout Pearl Harbor. Omnivorous in food habits, this solitary species was collected in nearly all fish trap sets during this study. Previous Pearl Harbor fish studies (Evans, 1974) identified the Pacific threadfin or "moi" (*Polydactylus sexfilis*) as a single piscine predator of maki maki. *A. hispidus* is a shoreline species which frequently inhabits pier and piling areas as well as vertical ledges in the harbor. Like other soft puffers or balloonfishes (family Tetraodontidae), this species is able to inflate its body with either air or water as a defensive response (Tinker, 1978). The flesh and viscera of *A. hispidus* are extremely toxic (Halstead, 1967). The global distribution of *A. hispidus* extends from Hawaii southward to the northern coast of Australia, westward through Micronesia, Melanesia and the Philippines through the East Indies and across the Indian Ocean to the east coast of Africa (Tinker, 1978). In Pearl Harbor this species appears to thrive in even the most stressed environments (Evans, 1974). For *A. hispidus*, there was no indication of adverse effects attributable to cooling water systems operation during this study.

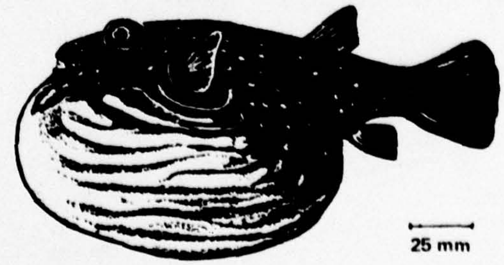

Figure A-16. *Arothron hispidus* (from Jordan and Evermann, 1903).

Caranx melampygus Cuvier and Valenciennes, 1833 is a fast-swimming, schooling, pelagic carnivore (figure A-17). The "omilu" is one of the most frequently caught "papio" (juvenile carangids) in Hawaii (Gosline and Brock, 1960); it is also known locally as "hoshi ulua" as an adult. "Ulua" refers to adult (greater than 5 kg) carangids of several species. *C. melampygus* is an excellent game fish which also has high commercial value (Gosline and Brock, 1960). This species is distributed from Hawaii southward into central Polynesia, eastward to western Central America and westward through Micronesia, through the East Indies and across the Indian Ocean to the coast of Africa (Tinker, 1978). In Pearl Harbor, *C. melampygus* has been observed to ingest various fishes (including "nehu," *Asterropteryx* and juvenile scarids) and a variety of decapod crustaceans, especially crabs and shrimp (Evans, 1974). During a feeding relationship study off Kona on the island of Hawaii, Hobson (1974) found that this species usually fed early and late in the day. Schools of juvenile *C. melampygus* (100–200mm in length) were commonly observed at all study sites during the present investigation. No adverse effects on this species due to cooling water systems were apparent during either field observations or analytical interpretation of data for this study.

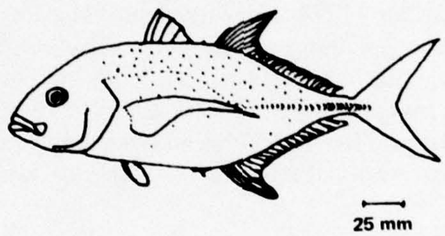

Figure A-17. *Caranx melampygus* (drawn by J. Grovhoug).

Parupeneus porphyreus (Jenkins, 1903), "kumu," a beautiful, deep red goatfish, is a highly-prized recreational and commercial species in Hawaii (figure A-18). This gregarious goatfish is primarily a benthic carnivore, using its chin barbels to probe the bottom substratum for demersal fishes and crustaceans (Evans, 1974; Hobson, 1974). The distribution of this species extends from Hawaii southward to central Polynesia and throughout adjacent Indo-Pacific regions. In Hawaii *P. porphyreus* is probably the commonest of the inshore species of this genus (Gosline and Brock, 1960). This species apparently thrives in the Pearl Harbor ecosystem, as it was the most commonly trapped and tagged species during intensive investigations in the harbor during 1971-1973 (Evans, 1974). "Kumu" were commonly observed and collected in traps at study sites during the present investigation. There was no evidence of adverse impact from cooling water systems on the distribution of this species within the harbor.

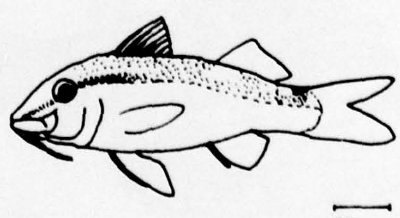

Figure A-18. *Parupeneus porphyreus* (drawn by J. Grovhoug).

The "nehu," *Stolephorus purpureus* Fowler, 1900 is the most important bait-fish for skipjack tuna ("aku") in the Hawaiian Islands (Gosline, 1951; Gosline and Brock, 1960; Uchida and Sumida, 1971). This Hawaiian anchovy (figure A-19) inhabits the quiet waters of bays and estuaries such as Pearl Harbor that have high nutrient loads and resulting high plankton concentrations to support "nehu" populations. Pearl Harbor is a major bait-collecting site for aku fishermen, and as such provides an important, commercially valuable resource. The distribution of *S. purpureus* is believed to be limited to Hawaiian waters (Tinker, 1978). Adult "nehu" are small (20-60mm), fragile, schooling fish which feed on various planktonic crustaceans such as copepods, crab larvae, shrimp larvae, ghost shrimp (*Lucifer*) and barnacle larvae (Hiatt, 1951), and spawn throughout the year in Hawaii (Tester, 1951). Predators on adult "nehu" in Pearl Harbor have been identified as *Caranx mate, C. melampygus,* and *Elops hawaiiensis* (Evans, 1974). In a comprehensive study of the distribution of "nehu" eggs and larvae, Au (1965) found that larvae were widely distributed throughout Pearl Harbor, while the demersal eggs were restricted to the vicinity of the entrance channel. McCain (1974) found "nehu" larvae to be considerably more concentrated in areas adjacent to the intake and discharge structures of HECo's generating plant in East Loch than other areas around Pearl Harbor. Comparative data indicate that populations of larval "nehu" were higher in Pearl Harbor than those estimated in Kaneohe Bay. During the present study, few larval fish were collected in tow net or filter-pump entrainment samples. "Nehu" larvae and eggs comprised a small percentage of total biota identified, and therefore, are not considered to be significantly affected by cooling water systems at the present study sites.

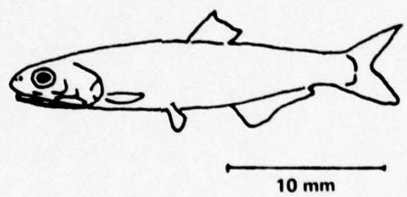

Figure A-19. *Stolephorus purpureus* (drawn by J. Grovhoug).

APPENDIX B

Cumulative Checklist of Organisms recorded during a study at three sites in Pearl Harbor, Oahu, August – October 1978

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Taxonomic Hierarchy	Genus/Species	Naming Authority/Date

Cyanophyta (blue-green algae)
- Oscillatoriales
  - Nostocaceae

Chlorophyta (green algae)
- Chlorophyceae
  - Ulotricales/Ulvaceae
    - *Ulva fasciata* Delile, 1813

Chrysophyta (golden-brown algae)
- Chrysophyceae (yellow-brown algae)
  - Silicophycidae
    - *Dictyocha?*
- Bacillariophyceae (diatoms)
  - Centrales
    - *Chaetoceros*
    - *Melosira*
    - *Skeletonema*
  - Pennales
    - *Navicula*
    - *Nitzschia*
    - *Thalassionema*

Pyrrophyta (fire algae)
- Dinophyceae (dinoflagellates)
  - Peridinales
    - *Dinophysis?*

Protozoa (protozoans)
- Sarcodina
  - Granuloreticulosia
    - Foraminifera, several unidentified spp.

Porifera (sponges)
- Demospongiae
  - Hadromerida
    - *Terpios zeteki* (de Laubenfels, 1936)
    - several unidentified spp.

Cnidaria (coelenterates)
- Hydrozoa
  - Hydroida
    - Bougainvilliidae
    - Clavidae
    - *Halocordyle disticha* (Goldfuss, 1820)
    - *Clytia hemisphaerica* (Linnaeus, 1767)
    - *Obelia dichotoma* (Linnaeus, 1758)
    - *O. bidentata* (?)
    - Sertulariidae
    - *Tubularia* sp.
- Scyphozoa
  - Rhizostomatida/Mastigiidae
    - *Phyllorhiza punctata* von Lendenfeld, 1884

Taxonomic Hierarchy | Genus/Species | Naming Authority/Date

- Cnidaria (coelenterates) (continued)
  - Anthozoa/Alcyonaria
    - Telestacea/Telestidae
      - *Telesto riisei* (Duchassaing & Michelloti, 1860)
  - Anthozoa/Zoantharia
    - Actinaria/Aiptasiidae
      - *Aiptasia pulchella* Carlgren, 1943
- Ctenophora (comb jellies)
  - Tentacula
    - Cydippida
      - unidentified ctenophore
- Platyhelminthes
  - Turbellaria
      - unidentified planarian
- Nemertea (rubberworms)
      - unidentified nemertean
- Nematoda (roundworms)
      - unidentified nematodes
- Annelida (segmented worms)
  - Oligochaetes
    - Plesiopora
      - unidentified tubificids
  - Polychaetes
    - Errantia
      - Aphroditidae/Polynoinae
      - Amphinomidae
      - Phyllodocidae
      - Hesionidae
      - Syllidae
      - Nereidae
      - Eunicidae/Eunicinae
      - Eunicidae/Dorvilleinae
    - Sedentaria
      - Spionidae
      - Cirratulidae
      - Chaetopteridae
      - Orbiniidae
      - Paraonidae
      - Ophelidae
      - Cossuridae
      - Capitellidae
      - Sabellariidae
      - Terebellidae
      - Sabellidae
      - Serpulidae/Spirorbinae
      - Serpulidae/Serpulinae
        - *Hydroides elegans* (Haswell, 1883)
        - *Hydroides* sp.

Taxonomic Hierarchy	Genus/Species	Naming Authority/Date

Sipunculida (peanut worms)
- unidentified sipunculids

Arthropoda (arthropods)
- Pycnogonida
  - Ammotheidae
    - *Ammothella biunguiculata* (Dohrn, 1881)
  - Callipellenidae
    - *Pigrogromitus timsanus* Calman, 1927
  - Phoxichilidiidae
    - *Anoplodactylus portus* Calman, 1927
  - Endeidae
    - *Endeis nodosa* (Hilton, 1942)
- Crustacea
  - Ostracoda/Myodocopa
    - *Conchaecia* sp.
    - *Cylindroleberis* sp.
    - *Paravargula* sp.
  - Ostracoda/podocopa
    - *Bairdia* sp.
  - Copepoda/Calanoida
    - *Acartia fossae* cf. *hamata* (Mori, 1937)
    - *Acrocalanus gracilis* Giesbrecht, 1888
    - *A. inermis* Sewell, 1912
    - *Calocalanus pavo* (Dana, 1949)
    - *Clausocalanus* sp.
    - *Pontellina* sp.
    - *Scolecithrix* sp.
    - *Undulina vulgaris* (Dana, 1849)
  - Copepoda/Cyclopoida
    - *Coryceus* sp.
    - *Oithona linearis* Giesbrecht, 1891
    - *O. nana* Giesbrecht, 1892
    - *O. plumifera* Baird, 1843
    - *O. simplex* Farran, 1913
    - *Oncaea venusta* Phillipi, 1843
    - *Oncaea* sp.
  - Copepoda/Harpacticoida
    - *Aegisthus* sp.
    - *Clytemnestra* sp.
    - *Euterpina acutifrons* (Dana, 1847)
    - *Microsetella* sp.
    - unidentified harpacticoids
  - Cirripedia
    - *Balanus reticulatus* Utinomi, 1967
    - *Balanus* sp. (juveniles)
  - Mysidacea
    - *Heteromysis* sp.

Taxonomic Hierarchy	Genus/Species	Naming Authority/Date

Arthropoda *(continued)*
  Crustacea (continued)
    Tanaidacea
      Apseudes sp. 1
      Apseudes sp. 2
      Anatanais insularis Miller, 1940
      Leptochelia dubia (Kroyer, 1852)
    Malacostraca/Isopoda
      Cirolana sp. cf. *parva*
      Mesanthura hieroglyphica Miller & Menzies, 1952
      Paracerceis sculpta (Holmes, 1909)
      Dynamenella sp.
    Malacostraca/Amphipoda
      Paracaprella pusilla Mayer, 1890
      Ericthonius brasiliensis Dana, 1852
      Podocerus brasiliensis Dana, 1853
      Stenothoe gallensis cf. also *S. valida*
      Lembos macromanus (Shoemaker, 1925)
      Corophium baconi Shoemaker, 1934
      C. insidiosum Crawford, 1937
      Photis hawaiiensis J.L. Barnard, 1955
      Elasmopus piikoi J.L. Barnard, 1970
      E. rapax Costa, 1953
      Leucothoe hyhelia J.L. Barnard, 1965
    Malacostraca/Decapoda/Natantia
      Lucifer chacei Bowman, 1966
      Palaemon pacificus (?) (Simpson)
      unidentified Palaemonidae juveniles
      Alpheus mackayi Banner & Banner, 1974
      A. rapacida deMan, 1911
    Malacostraca/Decapoda/Reptantia
      Thalamita integra Dana, 1852
      unidentified brachyuran larvae
      stomatopod alima larvae
Mollusca (mollusks)
  Gastropoda
    Mesogastropoda/Vermetidae
      unidentified vermetid spp.
    Mesogastropoda/Calyptraeidae
      Crepidula aculeata Gmelin, 1791
    Gastropod veliger larvae
  Bivalvia
    Mytiloida/Mytilidae
      Brachidontes crebristriatus (Conrad, 1937)
    Pteroida/Ostreidae
      Ostrea sp.

Taxonomic Hierarchy	Genus/Species	Naming Authority/Date

Mollusca (continued)
  Bivalvia (continued)
    Pteroida/Anomiidae
      Anomia nobilis Reeve, 1859
    Myoida/Hiatellidae
      Hiatella hawaiensis (Dall, Bartsch & Rehder, 1938)
    Bivalve veliger larvae
Ectoprocta (bryozoans)
  Gymnolaemata
    Ctenostomata/Vesiculariidae
      Amathia distans Busk, 1886
    Cheilostomata/Bicellariellidae
      Bugula neritina (Linnaeus, 1758)
      Bugula sp.
    Cheilostomata/Smittinidae
      Holoporella spp. (2)
      Watersipora edmondsoni Soule & Soule, 1968
Echinodermata (spiny-skinned animals)
  Ophiuroidea
      unidentified ophiuroids
  Holothuroidea
      unidentified holothurians
Chaetognatha (arrow worms)
      Sagitta enflata Grassi, 1883
      S. regularis Aida, 1897
Chordata
  Urochordata (tunicates & sea squirts)
    Ascidiacea
      Botrylloides sp.
      Symplegma connectans Tokioka, 1949
      Diplosoma macdonaldi Herdman, 1886
      unidentified didemnids
      unidentified solitary tunicates
    Larvacea
      unidentified appendicularian larvae
  Vertebrata/Pisces
    Chondrichthyes/Carcharhinidae
      Carcharhinus limbatus Muller & Heinle, 1841
        /Sphyrnidae
      Sphyrna lewini Griffith & Smith, 1834
        /Myliobatidae
      Aetobatus narinari (Euphrasen, 1790)
    Osteichthyes/Elopidae
      Elops hawaiiensis Regan, 1909
        /Muraenidae
      Gymnothorax undulatus (Lacepede, 1803)
        /Congridae

Taxonomic Hierarchy	Genus/Species	Naming Authority/Date

Chordata (continued)
    Vertebrata/Pisces (continued)
        Osteichthyes/Elopidae (continued)
            Conger cinreus (Ruppel, 1828)
                /Engraulidae
            Stolephorus purpureus Fowler, 1900
                /Synodontidae
            Saurida gracilis (Quoy & Gaimard, 1824)
                /Chanidae
            Chanos chanos (Forskal, 1775)
                /Hemiramphidae
            Hemiramphus depauperatus Lay & Bennett, 1839
                /Belonidae
            Tylosurus crocodilus (Peron & LeSuer, 1821)
                /Holocentridae
            Flammeo sammara (Forskal, 1775)
            Myripristis murdjan (Forskal, 1775)
                /Kuhliidae
            Kuhlia sandvicensis (Steindachner, 1876)
                /Apogonidae
            Foa brachygrammus (Jenkins, 1903)
            Apogon snyderi Jordan & Evermann, 1903
                /Carangidae
            Gnathanodon speciosus Forskal, 1775
            Caranx melampygus Cuvier & Valenciennes, 1833
            C. sexfasciatus Quoy & Gaimard, 1825
            C. mate Cuvier & Valenciennes, 1833
                /Mullidae
            Upeneus arge Jordan & Evermann, 1903
            Mulloidichthyes samoensis (Gunther, 1878)
            Parupeneus pleurostigma (Bennett, 1831)
            P. porphyreus (Jenkins, 1903)
                /Chaetodontidae
            Chaetodon auriga Forskal, 1775
            C. ephippium Cuvier & Valenciennes, 1831
            C. lunula (Lacepede, 1802)
            C. miliaris Quoy & Gaimard, 1825
                /Pomacentridae
            Abudefduf abdominalis Quoy & Gaimard, 1824
            Dascyllus albisella Gill, 1862
                /Mugilidae
            Mugil cephalus Linnaeus, 1758
                /Sphyraenidae
            Sphyraena barracuda (Walbaum, 1792)
                /Polynemidae
            Polydactylus sexfilis (Cuvier & Valenciennes, 1831)
                /Labridae

Taxonomic Hierarchy	Genus/Species	Naming Authority/Date

Chordata (continued)

Vertebrata/Pisces (continued)

Osteichthyes/Elopidae (continued)

Stethojulus balteata (Quoy & Gaimard, 1824)

/Scaridae

Calotomus spinidens Quoy & Gaimard, 1824

/Blenniidae

Omobranchus elongatus (Peters, 1855)

/Gobiidae

Ctenogobius tongarevae (Fowler, 1927)

Opua nephodes Jordan, 1925

Gnatholepis anjerensis (Bleeker, 1850)

/Eleotridae

Asterropteryx semipunctatus Ruppell, 1821

/Acanthuridae

Acanthurus dussumieri Cuvier & Valenciennes, 1835

A. xanthopterus Cuvier & Valenciennes, 1835

A. mata Cuvier, 1829

Zebrasoma flavescens (Bennett, 1828)

Naso brevirostris (Cuvier & Valenciennes, 1835)

/Zanclidae

Zanclus cornutus (Linnaeus, 1758)

/Ostraciontidae

Ostracion meleagris camurum (Jenkins, 1901)

/Tetraodontidae

Arothron hispidus (Linnaeus, 1758)

/Diodontidae

Diodon hystrix Linnaeus, 1758

D. holocanthus Linnaeus, 1758

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